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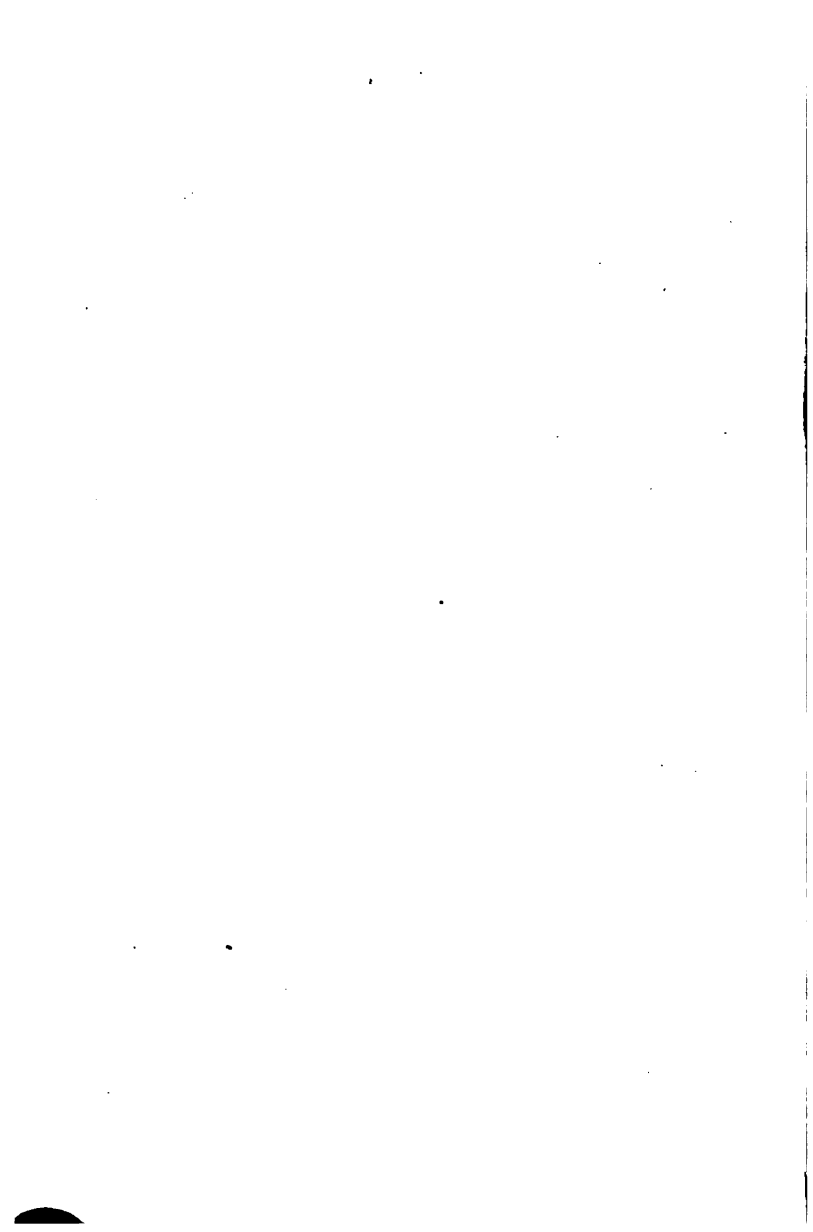
STEAM

AND THE

STEAM ENGINE:

LAND AND MARINE.

BY

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PREFACE.

THIS book is intended to give beginners an insight into the simple theory and arrangement of the Steam Engine. It has been the chief aim of the writer to make the subject as easy, practical, and perspicuous as possible, by omitting whatever is dry in theory, if not absolutely requisite, or likely to puzzle and confuse.

The author has keenly felt that a work of this kind was greatly wanted, and it has been his endeavour to supplement the design of the Publishers, in seeking to occupy a foremost place in supplying, in the best manner possible, the want so widely felt, so as to bring the Series of Text-Books, of which this volume forms one, within easy reach of every Student of Science in the Kingdom.

H. E.

January, 1873.

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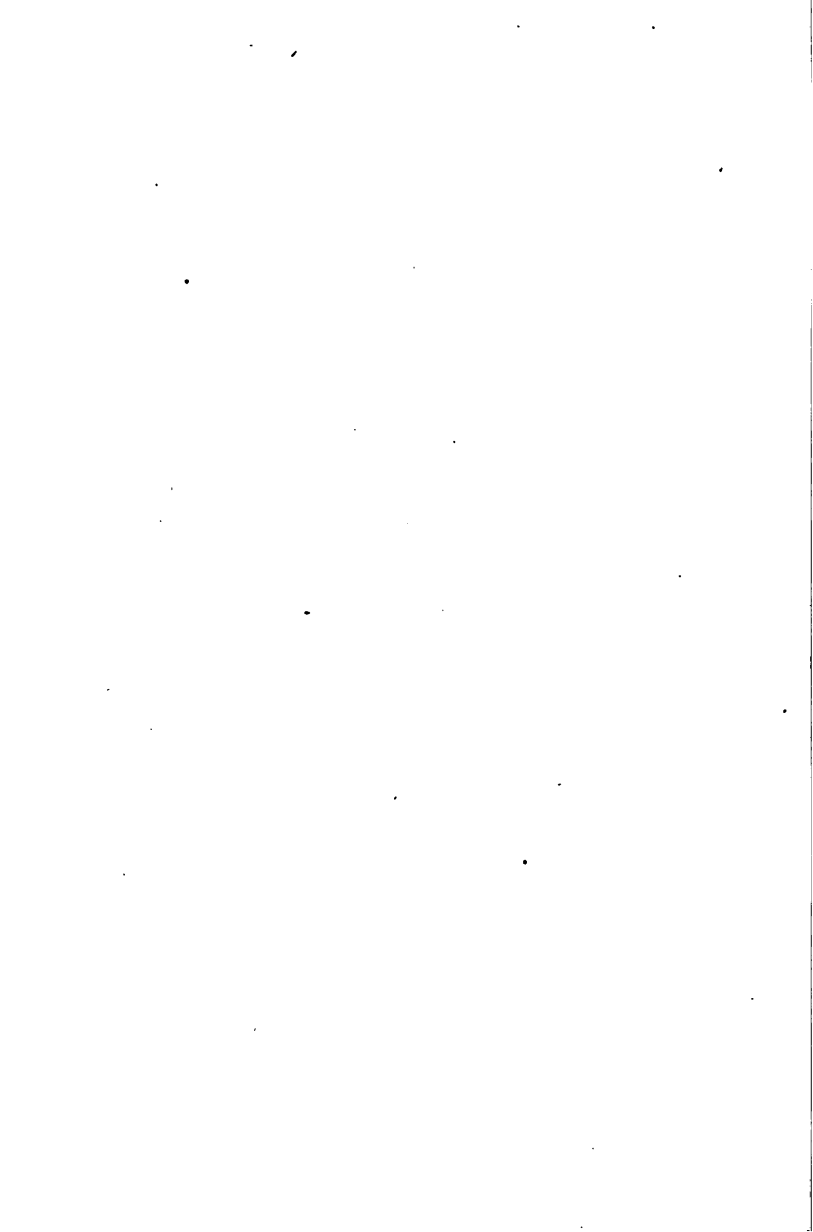
CHAPTER I.

HEAT.

Definition—Expansion of Bodies by Heat—The. Liquid and
Gaseous States of Matter—Co-efficient of Expansion—
Energy of Atomic Forces—Practical Illustrations—Tempera-
ture of Bodies, and Instruments for Measuring Temperature—
Thermometers—Comparison of Thermometers—Graduation
of Thermometers—Pyrometers—Capacity for Heat of Bodies
—Calorimeter—Conversion of Heat into Work and Work
into Heat—Consumption of Heat in Liquefaction and Vapor-
isation—Convection of Heat—Methods by which a Large
Mass of Water may become Heated—Conduction of Heat—
Good and Bad Conductors—Experimental Illustrations.

1. **Steam** is an elastic, invisible fluid generated from
water by heat.

2. **Steam is Invisible.**—If we watch closely steam as
it issues from a safety valve, a steam whistle, or even from
the spout of a common kettle, we shall see nothing, or it is
invisible. It is only at a distance from these orifices that
it is rendered visible by parting with its heat to the air.
When visible, properly speaking, it is no longer steam,
but vapour; although it is not always wise to separate
steam and vapour by such a hard and fast line. Some
authorities say when water passes away insensibly with-
out the mechanical application of heat it is vapour, but
when heat is directly applied to the water it passes away
as steam.

3. Steam is Elastic.—Take a cylinder or box, into which is tightly fitted a piston, and fill it with steam. If we now maintain the cylinder and steam at the same temperature, and apply a sufficient force to compress the steam into half the space, and then suddenly withdraw the force, the steam will again expand and fill the same space as before, driving the piston back again to its original position. The piston is returned to its place by the elastic force of the steam. Or we may illustrate the elasticity of steam much better thus: Suppose our cylinder full of steam, to be steam at a pressure of 15 lbs. on the square inch, and let the piston be at A B, and that from B to N be sixteen inches. If the piston be forced half-way down, or eight inches, to C D, then the steam, occupying one-half its former space, its pressure will be doubled, or on each square inch the pressure will be 30 lbs. Next force the piston to E F, four inches farther down, so as to reduce again the volume of the steam by one-half, or to compress it into one-quarter of its original volume, then the pressure will be again doubled, and will now be 30×2 or $15 \times 4 = 60$ lbs. on the square inch. If it be forced to G H, two inches still farther down, or the volume again decreased one-half, or occupying one-eighth of the original space, the pressure is now 60×2 or $15 \times 8 = 120$ lbs. on the square inch. We see by this illustration that the pressure increases as the space decreases. This is called Mariotte's or Boyle's law, and is generally expressed thus: *The temperature remaining the same, the volume of a given quantity of gas is in inverse ratio to the pressure which it sustains.*
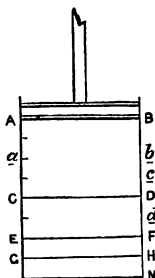
4. Latent Heat.—The heat not sensible to the thermometer is termed latent heat or hidden heat.

5. Heat or Caloric.—When heat is applied to bodies

they immediately expand, and when cooled they contract. When the sun shines upon the air it expands, rises up, and causes currents of air or wind. When the sun shines upon the sea the waters expand at the equator, and flow towards the north and south.

When heat is applied to bodies the molecules immediately begin to oscillate or vibrate to and fro—the quicker the vibration the more intense the heat; as they cool they vibrate more slowly, or lose their motion ; hence *heat is motion—the motion of atoms, and cooling is a loss of motion, or decrease of vibration.*

6. The Liquid and Gaseous State of Matter.—If sufficient heat be applied to the solid hard substance iron, it becomes a molten mass, and should a more intense heat be continued, the iron will pass off as an incandescent vapour or gas. The most familiar illustration we have of the liquid and gaseous state of matter is the common substance water. It is presented to us as the hard crystalline solid substance ice, as limpid water, and as gas in the form of steam, in each state it is endowed with perfectly distinct qualities. Our business is chiefly with those qualities presented to us when it is in the condition of a gas. Water, like every other substance (we will refer to the exceptions presently), expands by heat and contracts by cold. The liquid water itself expands by heat, but when the water is transformed to steam it occupies, in round numbers, 1700 times as much space, or, more exactly, 1669 times its volume. A cubic foot or cubic inch of water, evaporated into steam at the ordinary pressure of the atmosphere, fills a space equal to 1669 cubic feet or inches.

7. Co-efficient of Expansion.—Already it has been stated that all bodies upon being heated expand, and on cooling contract.

The amount a body expands in length, on receiving one degree of additional heat, is termed *the linear co-efficient of expansion.*

The amount the surface of a body expands, in receiving

one degree of additional heat, is termed *the superficial co-efficient of expansion.*

The amount a body expands in bulk, on receiving one degree of additional heat, is termed *the cubical co-efficient of expansion.*

The superficial co-efficient is generally double the linear, and the cubical three times the linear.

A gas or other elastic fluid, on being heated one degree centigrade, expands about $\frac{1}{273} = \cdot003666$ of its volume, or $\frac{1}{490}$ for each degree Fahrenheit. Supposing we have 273 cubic inches of steam or gas in a vessel in which it can expand, upon the application of heat sufficient to heat it one degree centigrade, it will expand *one* inch, and occupy a space of 274 inches, heated two degrees it will occupy a space of 275 inches, three degrees, 276 inches, etc.

Co-efficients of Expansion.—The following are the co-efficients of a few well known substances :—

Substance.	Linear Co-efficient.	Cubical.
Zinc	·0000297	·0000890
Lead	·0000284	·0000890
Cornish Tin	·0000217	·0000690
Silver	·0000191	·0000574
Brass	·0000185	·0000554
Copper	·0000171	·0000512
Gold	·0000151	·0000453
Wrought Iron	·0000118	·0000354
Platinum	·0000088	·0000264
Glass	·0000087	·0000254

8. Bodies Expand by Heat and Contract by Cold. —The law is almost universally true, that bodies expand by heat and contract by cold.

(*a*) The most familiar illustration we have of this law is in the expansion and contraction of water when under the influence of heat and cold. Take water at a temperature of 4°C. ; after the heat has been applied for a short time, it will begin to expand, and will continue to expand as the temperature increases, till it reaches the boiling point 100° C. After this, if we continue to apply heat,

no alteration will take place in the temperature of the water. The additional heat that passes into the water is employed in converting the water into steam. A cubic inch of water will supply 1669 cubic inches of steam, or nearly a cubic foot. The result of another experiment was that a gallon of water, evaporated at 100°C., produced nearly 1700 gallons of vapour. When cold is applied to this vapour it contracts to its original volume.

(b) In building such bridges as the Albert Bridge, Saltash, and the Britannia and Conway tubular bridges, spaces are left for the expansion and contraction of the iron. The difference between the lengths of these bridges measured during the extreme heat of summer and the extreme cold of winter, is considerable.

(c) Experience has taught us that, in laying down the rails for a railway, spaces of about two-eighths or three-eighths of an inch must be left to allow the rails to expand in length. Were this not done, the molecular force of expansion would be sufficient to draw the spikes or lift the sleepers and rails out of their places.

Mr. Stephenson once stated that, in consequence of laying three or four miles of line, near Peterborough, with close joints, the heat of the sun on a warm day caused such an extension that the rails and sleepers were lifted in one place from the ballast so as to form an arch fifty feet long and three feet high in the air.

(d) The simplest plan to separate a crank from a shaft on which it has been shrunk, and, in fact, to disconnect any rust joint, is to apply heat, when the bodies (being of different dimensions) expand unequally and separate.

(e) Many other illustrations might be given, as, when warehouses constructed with fire-proof floors, etc., have been destroyed by fire, the walls of the buildings which were considered indestructible, have been thrown down by the enormous expansion of the iron girders, tie-beams, etc. Wheelwrights and carriage-builders, when they wish to place the tire upon a wheel, expand it by placing

it in a fire, then slip it upon the wheel, and suddenly cool it, when the molecular power of contraction holds and binds the whole wheel firmly together.

9. Bodies Contract by Cold.—This may be illustrated by most of the foregoing instances of expansion by heat. A cubic foot of steam becomes a cubic inch of water when contracted by cold. The ends of railway rails are more widely separated in winter than in summer. This point will be further illustrated under the heading of Molecular Force; but a good illustration will be found in the method by which collars are shrunk on a shaft. A neat way of putting collars on heavy marine shafts where the journals come, is this—bosses are turned on the shaft, and two ribs, three or four sixteenths of an inch high, are left on the bosses for the collars, which must be prepared in the lathe, and heated and slipped over the ribs, then, upon contracting with the cold, they will firmly grip the shaft.

10. The Enormous Power of Expansion and Contraction.—When bodies expand, the molecules of which they are composed are pushed farther asunder by the oscillatory motion communicated to them. The heat may be described as entering the substance, and immediately setting to work to separate the particles. The power or energy they exert to do this is immense. The following are illustrations of the energy of molecular forces. We have already mentioned several under the heads Expansion and Contraction :—

(*a*) When a dry wooden wedge is driven into the crevice of a rock, and moistened with water, the wedge swells and splits the mass. Thus many accidents have happened to grinders through the wedges swelling between the axle and the stone, and causing the latter to burst. Of course, in this case, centrifugal force assisted the wedges.

(*b*) When a rope is moistened, the diameter becomes larger, and the rope shorter, for the fibres are drawn in by this enlargement. It is said that, in lifting the statue

of Nelson into its place in Trafalgar Square, the ropes had stretched through the great weight, and the blocks were close to each other. The whole operations would have failed, although the hero was within a very short distance of his place, had not a sailor cried out, "Wet the ropes." The hint was immediately taken, and the work accomplished.

(c) Water is turned into steam by heat; this heat endows the water with (atomic) force sufficient to drive the locomotive, to propel the steamship round the world, to work the mill, the forge, the hammer, the pump, etc.

(d) If the wall of a large building be bulging out, and an iron girder placed in a proper position, the power of contraction by cold will subserve the purpose of bringing it into the perpendicular. It has been done on a large scale in France. A girder (or girders) was fitted across the building, with strong wall plates at each end, and screwed up as tightly as possible. All along the girder was applied a number of gas jets, and as it expanded by the heat, the screws were tightened. The girder was then allowed to cool, and the strain of its contraction was sufficient, after repeating the process several times, to draw the walls into the perpendicular.

(e) We may also add, that the Gulf Stream and the trade winds are caused by the atomic force of heat (but see Convection).

11. Molecular Force, or Atomic Force.—All molecules are under the influence of two opposite forces. The one, *molecular attraction,* tends to bring them together; the other, *heat,* tends to separate them; its intensity varies with its velocity of vibration. *Molecular attraction* is only exerted at infinitely small distances, and is known under the name of *cohesion, affinity,* and *adhesion.*

By the force of *cohesion* everything is held together. Heat and cohesion are antagonistic to each other. When heat predominates in liquids they become gases, when cohesion solids.

Chemical affinity is a form of molecular force that greatly assists the engineer; by chemical affinity the various products of combustion in the air and the fuel combine, and in the act of combination produce the heat necessary for his purpose.

Adhesion is the molecular force exerted between bodies in direct contact. When two pieces of lead have their pure metallic surfaces laid bare, and are put together with pressure and a twist, they become united so as to require considerable force to separate them. When we come to speak of the marine engine, and the way in which the thrust of the shaft of the screw is received upon the thrust block, reference will be made to the method first adopted to receive the thrust, namely, on a series of discs, which sometimes became so clean for want of attention to the lubrication, that the pure metallic surfaces firmly united by the molecular force of adhesion, and the shaft broke at a distance from the discs.

Heat is another atomic force, which, by causing bodies to expand and contract, exerts enormous power as already illustrated.

12. Temperature of Bodies.—Temperature of a body is the measure of the intensity of heat in the body. A body may contain a large amount of heat that is not sensible to a thermometer.

13. Thermometer is an instrument for measuring the temperature or intensity of heat in a body. It is constructed on the principle that bodies expand and contract when subject to cold and heat with a certain amount of regularity within certain limits. The ordinary thermometer consists of a closed glass tube with a capillary bore, terminating at the lower end in a bulb, which, with the bottom part of the tube, contains mercury or spirits of wine, etc., the rest of the tube being a vacuum. A graduated scale by the side of the tube indicates the amount of expansion or contraction of the mercury. There are three kinds of thermometers.

(1) Fahrenheit's, chiefly used in England and America.

(2) That of Celsius, chiefly used by the French.

(3) That of Reaumur, used by the Germans.

14. (1) **Fahrenheit's Thermometer.**—The increment of expansion by heat and contraction by cold of mercury is practically the same for all temperatures for which a thermometer can be employed. Hence mercury is much better adapted for a thermometer than water or spirits of wine. Fahrenheit named the greatest degree of cold attainable in his time by artificial means 0° F., and the freezing point 32°. Hence the graduation of his thermometer commences at 32° below the freezing point, and between freezing and boiling there are 180°, so that the boiling point is 212° F.

FAHRENHEIT CENTIGRADE REAUMUR
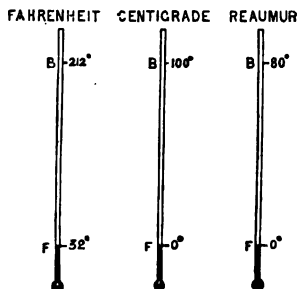
THERMOMETERS.

15. (2) **Centigrade Thermometer.**—The freezing and boiling points in the centigrade thermometer are 0° and 100° respectively. The method of indicating the measure of heat, termed centigrade, is found so convenient that it is fast superseding Fahrenheit.

16. (3) **Reaumur**, or Romer, introduced a much more arbitrary division of the scale. He called the freezing point 0°, the boiling point 80°.

We now see that in Fahrenheit's scale there are 180° between the freezing and boiling points, in the centigrade 100°, in Reaumur 80°.

Rules to compare the reading of one thermometer · with that of another :—

(1) To convert Fahrenheit's degrees to centigrade—
    Subtract 32°, then multiply by 5, and divide by 9..

(2) To convert centigrade to Fahrenheit—
    Multiply by 9, divide by 5, and add 32°.

B

(3) To convert centigrade to Reaumur—
   Multiply by 4 and divide by 5, or subtract one-fifth.

(4) To convert Reaumur to centigrade—
   Multiply by 5 and divide by 4, or add one-quarter.

(5) To convert Fahrenheit to Reaumur, or Reaumur to Fahrenheit—
   First bring them into centigrade, then reduce to
      Fahrenheit or Reaumur, whichever may be
      required.

Exercises on the reduction of the number of degrees of one thermometer to an equivalent number of another, will be found at the end of the chapter.

17. Pyrometers.—Pyrometers are used for measuring intense temperatures.   It is evident to the most casual observer that the thermometer will measure a degree of heat but little beyond the temperature of boiling water. To measure the intense heat of the kiln of the porcelain manufacturer, the puddling furnace, the blast furnace, the boiler furnace, flues, etc., requires instruments of perfectly different construction.   These are found in such as Daniell's Pyrometer, Wedgewood's, the Sevres, Lavoisier and La Place's, Houldsworth's, etc.

Daniell's Pyrometer consists essentially of a small bar of platinum and a scale.   A solid bar, in length about eight inches, is cut out of a piece of black lead earthenware, down its centre is drilled a hole reaching nearly to the bottom.   Into this is inserted a tube of platinum reaching down to the end of the hole, leaving room at the top to allow a small tube of porcelain to be placed in, and to touch the end of the platinum.   This tube of porcelain is called the *index*.   The whole is named the *register*.   When it is desirable to ascertain the temperature of a heated body, furnace, etc., this is placed within the heat, and sufficient time allowed for it to acquire the same temperature. When it is withdrawn, it is found that the heat has expanded the platinum, which, in its turn, has driven out

the porcelain tube a certain space, according to the intensity of the heat; the porcelain is prevented from returning by a platinum strap.

The *Register* is, after it has cooled, next applied to a scale properly graduated, to enable the observer to read off easily the change in temperature.

18. **Unit of Heat.**—A unit of heat is the amount of heat necessary to raise the temperature of a pound of water one degree. Suppose a pound of water to be raised from 10°C. to 20°C., it has received ten additional units of heat; if five pounds of water be raised 5°, each pound has received five units of heat, and the whole twenty-five units. If we raise the temperature of half-a-pound of water 10°, we communicate to it *five* units of heat.

19. **Capacity for Heat of Bodies.**—The capacity for heat of bodies means their power of storing up heat. To work the same change of temperature in different bodies requires different amounts of heat. A given quantity of heat put into one body will cause a greater amount of motion than when put into another. Suppose, for instance, we throw six balls, the same size, of silver, tin, bismuth, copper, lead, and iron into boiling water, each will soon acquire the temperature of the boiling water, 100°C.; now take them out of the water, it will be found that you can almost at once handle the bismuth and lead, soon after the tin, then the silver, last of all the copper and iron remain hot the longest. The reason is this, that to raise the lead and bismuth to the temperature of 100°C. requires much less heat than to raise the tin. Tin requires less than silver, silver less than copper, and iron more than either; and, therefore, having more heat it takes a longer time to lose the motion. If we had taken the same balls and put them upon a thin cake of wax after heating them in boiling oil or water, it would be found that the iron would melt and fall through the wax first, the copper next, silver next, perhaps, if the wax were sufficiently thin, while the lead and bismuth

would not get through at all. The reason is this, the iron has the greatest specific heat, or it has stored up more heat than the others, and, therefore, it has enough to impart to the wax to melt it. The same with the copper, while the bismuth and lead, having a less capacity for heat than the others, they have less to give up, or less motion to impart to the wax to melt it and work their way through.

20. The Calorimeter is not used to measure the temperature of a body, but to ascertain the total amount of heat in it, or to find the specific heat.

Two similar metallic vessels are placed, one within the other, so as to leave a space between them. This space is filled with pounded ice, while a discharge pipe proceeds from the bottom of the external vessel to carry off all water that may be produced through the liquefaction of the ice by the external air. A third, and nearly similar vessel, is placed within the second, leaving a space between it and the second vessel, which is also filled with pounded ice; a second discharge pipe (with a stop cock) proceeds from the second vessel without communicating with the outside one. Each vessel is provided with its proper cover. It is obvious that the ice in the inner space cannot be affected by the temperature of the external air when the calorimeter is closed. The substance, whose specific heat we wish to ascertain, is placed, after observing its temperature, within the third or inner vessel. It is perfectly clear that any heat the body may contain, will communicate or lose its motion to the ice in the *second* space, or the ice will take up the heat from the substance as latent heat, and become converted into water; this is then allowed to pass through the discharge pipe leading from the inner vessel, and is collected. This water will at all times be proportional to the heat stored up in the given substance placed within the calorimeter.

By the calorimeter, it has been ascertained that to raise the temperature of water 1°, requires thirty times as much

heat as would be required to raise mercury 1°. Or the same heat that would raise 1 lb. of water 1°, would raise the temperature of 30 lbs. of mercury 1°; and this is what is meant when we say the specific heat of mercury is $\frac{1}{30}$ or ·03 that of water. Iron requires $3\frac{2}{8}$ more heat than lead to work in it the same change of temperature; practically, this means that lead will heat $3\frac{2}{8}$ times quicker than iron; at the same time it will cool very much more quickly than iron. It is obvious that to heat 2 lbs. of water 1°, requires twice as much heat as to heat 1 lb. of water 1°. The relative quantity of heat necessary to produce the same change of temperature in different bodies is their specific heat. We said the capacity for heat of water was thirty times that of mercury; hence this latter substance is so well adapted for thermometers; we see at once how sensible it must be to the least accession or subtraction of heat. Again, the capacity for heat of air at constant pressure, is about one quarter that of water, or more accurately ·237; hence 1 lb. of water, whose specific heat is 1, on losing 1° of heat, will increase the temperature of $(\frac{1}{·237} =)$ 4·2 lbs. of air 1°. But water is 770 times heavier than air. Hence if we compare volume instead of weight, a cubic foot of water, on losing 1° of temperature, will increase that of $770 \times 4·2 = 3234$ cubic feet of air 1°.

Capacity for heat may be defined as the quantity of heat necessary to raise the *same weight* of different substances through the same *number of degrees* of temperature; but it must not be defined as the amount of heat necessary to raise a pound weight of a given substance one degree in temperature, or else we shall confound it in the case of water with the unit of heat. Capacity for heat is found thus: one, two, three pounds, ounces, etc.; any weight may be chosen, of any substance, and heated so many degrees, one, two, three, etc. (generally heated in boiling water), and then put into the calorimeter, then according to the quantity of ice melted we have the capacity for heat. The quantity each substance liquefies

is noted, the whole compared with water as a standard, and the capacity for heat determined.

The following are the specific heats, or capacity for heat, of a few well known substances :—

Bismuth,...... ·0308	Copper,......... ·0949	Air, ... ·237
Lead,.......... ·0314	Iron, ... ·1098	Steam,...... ·4805
Mercury,...... ·0333	Glass, ... ·1770	Ice,.......... ·504
Platinum,..... ·0355	Sulphur, ... ·1844	Water, ...1·000
Silver, ... ·0557	White marble, ·2158	

21. Convection—Methods by which Large Masses of Air or Water become Heated.—"Convection is the transfer of heat by sensible masses of matter from one place to another." Water can only be heated by convection; it is scarcely possible to heat it by conduction. Our rooms are ventilated by convection, smoke ascends the chimney by the same principle, and all our winds and currents, in both air and water, are caused by this convection. The wind-sails of a ship afford an instance in which this law of nature is made available for ventilation.

If A B be a glass vessel or large Florence flask filled with water, when heat is applied at A, the water near A is immediately heated and expanded, and becoming specifically lighter rises up, and the colder water from above falls down to supply its place; this continual change goes on as long as the heat is applied at A, and is called convection. If a little cochineal be placed in the water, it will sink to the bottom of the flask, and heat being applied as before, the cochineal directly leaves the bottom, ascends up the middle, and then descends by the sides, returning again to the heat. By this simple experiment the action of convected water is made visible to the eye.
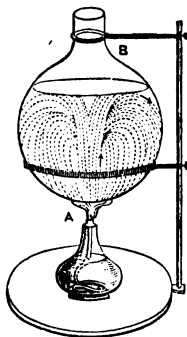
CONVECTION OF WATER.

Let C D be a large test-tube filled with water, and held by an holder in the position indicated by the figure; then let heat be applied at D, it will be found almost impossible to heat the water in the test-tube, for the heated or convected water rises perpendicularly up from the heat, confining itself to the top of the tube, and scarcely any heat is *conducted* downwards, for, of course, the convected or light water cannot run down, or mix itself with, or rather communicate its motion to, the heavier water below. Large masses of water can only be heated by convection, and therefore all furnaces should be placed as low down in the boilers as possible, while below the bars there should be but little if any water.

CONDUCTION OF WATER.

A patent fire-door is used for boilers, which is nothing but the application of the principle of convection : the doors are made with front and back plates, and hollow within. In the front plate are a few openings, one to one and a half inches in diameter, the back plate is thoroughly perforated with smaller holes. The air goes in at the bottom of the front plate, and out at the top, carrying off the heat, so that the front of the door is never heated to redness, the current of convected air carrying off the heat. In precisely the same way the funnels of steamers are kept cool, and passed through the wood of the decks. A casing is placed entirely round the funnel, passing into the engine-room, and sometimes spreading out over the boilers. A stream of air then continually runs up between the funnel and the casing ; this air takes the heat out of the funnel as it passes upwards, and keeps it from becoming too hot. Holes are often made at the bottom of the casing for the passage of additional air.

22. **Latent Heat of Water (or Ice).**—If a pound of ice at 0°C., be mixed with a pound of water at 79°·4C.,

the water will gradually dissolve the ice, being just sufficient for that purpose, and the residuum will be two pounds of water at 0°C. The 79·4 units of heat which are apparently lost, have been employed in performing a certain amount of work, *i.e.*, in melting the ice or separating the molecules and giving them another shape, and as all work requires a supply of heat to do it, this 79·4 units have been consumed in performing the work necessary to melt the ice, and is termed the **Latent Heat of Water.** If the pound of water were re-converted into ice, it would have to give up the 79·4 units of latent heat; hence we see why it should be called the latent heat of water, and not the latent heat of ice. The three forms of water are, then, (1) a solid, as ice; (2) a liquid, as limpid water; (3) a gas, as steam.

23. Latent Heat of Steam—The latent heat of steam at a pressure of 15 lbs., or thirty-two inches of mercury, is 537°·2C. We will describe an experiment which will help to illustrate this point, and fix the fact in the memory. Suppose that we have two very small vessels connected at their tops by a tube. Let one contain a pound of water, at the temperature of 0°C., and the other five and a half pounds, at the same temperature. If a spirit lamp be applied beneath the vessel containing the one pound of water, its temperature will gradually rise to 100°C., when ebullition will begin, and if the heat be continued, the water will not increase in temperature, but will pass off as steam along the tube to the second vessel, where the five and a half pounds of cold water will condense the steam and absorb the heat, which first enters and passes from the one pound, as long as the spirit lamp is applied to it. This operation of condensation and absorption will continue until the one pound of water is all converted into steam and re-converted into water. At the moment that the evaporation of the pound of water is completed, the heat transferred by the steam from one vessel to the other will cause the five and a half pounds of water to boil. It will be found that

there are now in the second vessel six and a half pounds
of water, at a temperature of 100°C.   As the 1 lb. takes
100 units of heat to make it boil, the 5½ lbs. take
5½ × 100 = 550 units; or, as there are 6½ lbs. of
water in B, the total quantity of heat is 100 × 6½ = 650
units of heat.   The boiling water, the one pound, never
exceeded a temperature of 100°, all the rest of the heat
went to evaporate the water; and as we know there are
650 units of heat in the 6½ lbs., therefore the latent heat of
steam is 550.   Exact experiments make the 5½ lbs. 5·372.
Hence the latent heat deduced from the experiment will
be 5·372 × 100 = 537·2.   This 537°·6 C., or 966°·6 F., is the
latent heat of steam. In making the experiment, ounces or
smaller quantities of water are employed, and not pounds.

**24. Consumption of Heat in Liquefaction and Va-
porisation.**—This is but another way of putting the facts
connected with the latent heat of water and steam. We
have seen that the latent heat of water is 79°·4C., or to
liquefy a given quantity of ice requires this amount of
heat; to raise the water to its highest temperature con-
sumes 100°C. more; next, to vaporise it consumes
537°·2C.

When heat is imparted to a body its atoms push each
other asunder, and the molecules commence to oscillate
more or less rapidly.   The more intense the heat the
quicker the particles oscillate; by raising the tempera-
ture you increase the oscillations, while cooling is a
decrease of vibration, or loss of motion.

25. Conduction.—If we place one end of a poker or
piece of iron in the fire, the molecules of the iron in the
fire immediately begin to oscillate, and each molecule
strikes its neighbour, passing the motion on, so that the
end of the poker out of the fire also becomes warm.   The
process by which the heat is passed up the poker is called
conduction.   There are good and bad conductors.   The
metals are generally good conductors, and the earths, saw-
dust, ashes, stone, glass, chalk, etc., bad conductors.
Silver is one of the best conductors.   If we call its power

of conduction 100, that of copper is 74, of gold 53, iron 12, lead 9, bismuth 2. A knowledge of this property of heat will teach an engineer on what to bed or surround his boiler, so that the least possible heat may be conducted out of it; also, in what he may case his steam pipes, cylinder, etc., to attain the same end.

The following are a few simple illustrations of the principle of conduction :—If a short piece of iron and a piece of glass the same length and size be placed in the fire, a little time afterwards we may handle the glass at the farther end, but not the iron, because the motion of the heat has passed up the iron more readily than up the glass. Again, if we obtain two short bars, one of platinum and another of tin, and fasten along them, by means of wax (which melts at $16^\circ\frac{1}{9}$C.), a row of small balls, then bring the two ends together in the flame of a burner, so that they shall be subject to the same heat, we shall find that the balls will drop off three times faster from the platinum rod, by means of its superior conductibility, than from the tin. The same experiment can be tried with rods of copper and iron, when they will fall more rapidly from the better conductor of the two, copper. As a rule, conduction is most strongly exhibited by solids, particularly by metals. Dense bodies (not including earths) are the best conductors, and light and porous ones the worst—the latter being non-homogeneous and not capable of communicating the motion or passing it on. Feathers, down, flannels, fur, blankets, woollens, etc., keep us warm because they are bad conductors, and will not allow the motion to pass from the body. On the same principle a few sheets of newspaper placed on a bed keep the sleeper warm. Liquids and gases are generally very bad conductors of heat.

26. Conversion of Heat into Work and Work into Heat.—Loss of heat is loss of work. It is the province of the engineer to convert heat into work, and to let none escape until it has done its duty. The most familiar illustration we can give is the locomotive. Fire is put

under the boiler, the heat converts the water into steam, which drives the engine and train; before the train can be stopped the whole moving force must be destroyed, which is effected by shutting off the steam and putting on the brake, when the force that moves the train is re-converted into heat, and sparks and fire issue from the brake. So that the work, or moving force, is turned into heat. When a carriage or waggon is going down a hill, the drag is put on to destroy the moving force, which it does by converting it into heat, and making the drag very hot. We must remember, at the same time, that the horses drawing the carriages convert the heat of their bodies, supplied and constantly renewed by the food they eat, into work, part of which work we have just shown is re-converted into heat in the drag in going down hill.

QUESTIONS AND MATHEMATICAL ILLUSTRATIONS FROM EXAMINATION PAPERS.

1. Convert 18°·5 C. to Fahrenheit (1866).
   Since 100°C = 180°F. (between freezing and boiling)
   ∴ 5°C. = 9°F.
   ∴ 18°·5C. = 65°·3F.

$$\begin{array}{r} 9 \\ \hline 5)166\cdot5 \\ \hline 33\cdot3 \\ 32 \\ \hline 65°\cdot3\,\text{F.} \end{array}$$

add so that the starting point may be 32° below freezing.

2. What degree on the centigrade thermometer corresponds to 158° on Fahrenheit's?

By the same reasoning as in the previous question, but subtracting 32° to start from the freezing point,

$$158°\,\text{F.} = 70°\,\text{C.}$$

$$\begin{array}{r} 32 \\ \hline 126 \\ 5 \\ \hline 9)630 \\ \hline 70°\,\text{C.} \end{array}$$

3. Reaumur's scale shows 45°, what is the corresponding temperature (1) on the centigrade? (2) on Fahrenheit's scale?

Centigrade.	Fahrenheit's.
80° R. = 100° C.	Instead of converting the 45°
∴ 4° R. = 5° C.	R. to F., we will convert to
∴ 45° R. = 56°¼ C.	56°¼ C. to F.

$$\begin{array}{r} 5 \\ \hline 4\,)\overline{225} \\ \hline 56\tfrac{1}{4}\ \text{C.} \end{array}$$

$$\begin{array}{r} 56\tfrac{1}{4}\ \text{C.} = 133\tfrac{1}{4}\ \text{F.} \\ 9 \\ \hline 5\,)\overline{506\tfrac{1}{4}} \\ \hline 101\tfrac{1}{4} \\ 32 \\ \hline 133\tfrac{1}{4}\ \text{F.} \end{array}$$

4. The linear co-efficient of expansion of iron is ·0000123 for 1° C. I have a rod of iron 20 feet long, and heat it from 20° C. to 290° C., what is the increase in length?

The temperature is raised 290° − 20° = 270°

For 1° C. each foot of iron increases ·0000123 feet in length
For 270° C. „ „ „ ·0000123 × 270 „
For 270° C. 20 feet „ „ ·0000123 × 270 × 20 „
= ·06642 feet = ·79704 inches, or over half an inch.

5. The co-efficient of expansion of gas is $\frac{1}{273}$ for one degree centigrade, find the increase in volume of 100 cubic feet of gas heated from 10° C. to 100° C.

The temperature of the gas is raised 100° − 10° = 90° C.

1 cubic foot on being heated 1° C. increases $\frac{1}{273}$
1 cubic foot „ „ 90° C. „ $\frac{90}{273}$
100 cubic feet „ „ „ „ $\frac{90 \times 100}{273}$
= 33 nearly
∴ Volume of the 100 cubic feet after being heated = 100 + 33 = 133 cubic feet.

6. Convert 100° C. to Fahrenheit. *Ans.* 212° F.
7. Express 28° F. in degrees centigrade. *Ans.* −2°⅔ C.
8. What degree centigrade and Fahrenheit corresponds to 80° R.? *Ans.* 100° C., and 212° F.
9. What degree centigrade corresponds to 100° R.?

Ans. 125° C.

10. The linear co-efficient of expansion of copper is ·0000171. How much will a rod 10 ft. long increase in length if heated from 0° C. to the temperature of boiling water?

Ans. nearly ¼ inch.

11. A brass letter is attached to the glass of a window, find how much the amount of expansion varies between the extreme heat of winter and summer, extreme of winter being − 3° C., extreme of summer 35° C.; the co-efficient of expansion of glass is ·00000876, and of brass ·0000185. *Ans.* ·00444144 inches.

12. The temperature of 20 cubic feet of gas is increased from 14° C. to 49° C., find the increase in volume and present volume.
Ans. 2·56 and 22·56 cubic feet.

13. If 40 volumes of gas have their temperature raised 60° C., what is the increase? *Ans.* 8·79 volumes.

14. Explain what is meant by capacity for heat and latent heat. What is the latent heat of steam at the ordinary atmospheric pressure (1863)?

15. Distinguish between conduction and convection. Mention some substances that are bad conductors, and state to what uses they are applied in the steam engines (1863).

16. Describe the several methods by which heat is propagated. Explain the terms capacity for heat and latent heat. What is the latent heat of steam (1864)?

17. What is meant by temperature? What are the general effects of adding heat to or subtracting it from a body (1865)?

18. A centigrade thermometer marks 5°, what will a Fahrenheit thermometer mark (1865)? *Ans.* 41° F.

19. Describe Daniell's pyrometer. For what purpose is it used (1865)?

20. Define capacity for heat, latent heat, and unit of caloric (1865).

21. Show how to graduate a thermometer.

22. Why is it necessary to take the height of the barometer in account in determining the boiling temperature (1866)?

23. Show how to convert degrees on a centigrade into degrees on Fahrenheit's scale.

24. What temperature F. corresponds to 49°·5 C. (1866)?
Ans. 121°·1 F.

25. What is meant by latent heat? Show under what circumstances heat becomes latent (1866).

26. What do you understand by conduction and convection as applied to heat (1867)?

27. What is the latent heat of steam? How is its amount ascertained (1867)?

28. What is the distinction between sensible and latent heat? Describe an instrument for measuring the former (1868).

29. Under what circumstances generally (1) does heat become latent? (2) does latent heat become sensible?

30. What amount of latent heat becomes sensible when ice is thawed into water (1868)?

31. Show how a thermometer is graduated. Compare the graduations on Fahrenheit's, Reaumur's, and the centigrade scale. Reaumur's scale shows a temperature of 15°, what will the centigrade and Fahrenheit's scales respectively show for the same temperature (1868)? *Ans.* 18°¾ C. and 65°¾ F.

32. What do you understand by the conduction of heat?

Mention one or two good, moderate, and bad conductors of heat (1869).

33. How can it be shown that the temperature at which water boils depends upon external pressure? What is high pressure steam (1869)?

34. Under what circumstances does heat become latent?

STEAM, SALT WATER, AND INCRUSTATIONS.

27. **Vapour and Steam.**—Steam was defined as an
elastic invisible fluid, produced from water by the appli-
cation of heat.   So long as it is invisible some autho-
rities count it steam, and as soon as it becomes visible
they call it vapour.   Others, again, give the term steam
to all vapour produced artificially by heat; when water
passes away insensibly, as through the influence of the
sun or air, it is called vapour.   *Evaporation* is the act of
converting water into vapour.   *Liquefaction* is the act of
converting a solid into a liquid, or a gas into a liquid.
Ice is converted by heat from a solid state to a liquid
condition.   Heat is the sole agent in the liquefaction of
solids; on the contrary, cold will liquefy certain gases,
while it will render some liquids, as water and mercury,
solids.

28. **Boiling Point of Fresh and Salt Water.**—Speak-
ing of the thermometer, it was stated that 100°C., 80°R.,
and 212°F., marked the boiling point of water respec-
tively on each system of graduation.   The boiling point
of a liquid is defined as "that temperature of the liquid

at which the tension of its vapour overcomes the resistance of the atmosphere." At the sea level, fresh water is found to boil at a temperature of 100°C., and for every 1062 feet that we ascend in vertical space, water will boil at a temperature of 1°C. less, the barometer standing in such cases at about 30 inches of mercury. The reason why water will boil at a lower temperature as we ascend, is, that the tension of its vapour meets with less resistance from the pressure of the atmosphere, and therefore *ebullition* takes place earlier. Sea water is heavier than fresh, in the proportion of 1 : 1·024. In consequence of this, salt water boils at a higher temperature than fresh water, because the tension of the vapour has a greater resistance to overcome in separating itself from the water. Sea water with $\frac{1}{30}$ of salt in it, at a pressure of 15 lbs. on the square inch, boils at a temperature of 100°$\frac{2}{3}$C., with $\frac{2}{30}$ of salt it boils at 101°$\frac{1}{3}$C., with $\frac{3}{30}$ at 102°C., etc. Thus the saltness of the water influences the temperature at which sea water boils. As the boiling point varies with the pressure of the atmosphere, so precisely in the same way the pressure of the steam upon the surface of the water in a boiler will have a tendency to raise the boiling point, because the tension of the vapour has a greater pressure or resistance to overcome before it can free itself from the water. When fresh water is used in a boiler, if we know its temperature we can tell the pressure, and if we know the pressure we can tell the temperature.

TABLE OF PRESSURES AND TEMPERATURES.

Pressure in lbs. per sq. in.	Temperature Centigrade.	Pressure in lbs. per sq. in.	Temp. C.	Pressure in lbs. per sq. in.	Temp. C.
15 lbs.	100°	55	142°·4	100	165°·3
20 lbs.	109°	60	145°·6	105	167°·3
25 lbs.	116°	65	148°·4	120	172°·9
30 lbs.	121°·7	70	151°·2	135	178°·
35 lbs.	126°·8	75	153°·8	150	182°·6
40 lbs.	131°·$\frac{1}{2}$	80	156°·3	165	187°·
45 lbs.	135°·4	85	158°·8	180	190°·9
50 lbs.	139°	90	161°	195	194°·6

The lesson to be learnt from the foregoing table is this, that if we find that the pressure gauge of a boiler using fresh water stands at 40 lbs., then the temperature of the water in the boiler is 131°⅓ C.; or, on the contrary, if by a thermometer we can ascertain that the temperature of the boiler water is 131°⅓ C., we know that the steam pressure *in the boiler* must be 40 lbs.

29. Salt in Sea Water and in a Marine Boiler.—As water evaporates, the steam passes away, leaving all impurities behind—whatever solid substances may be in solution in the water they remain in the boiler; hence a marine boiler using sea water becomes a large evaporating salt-pan, unless steps be taken to get rid of the salt.

30. Analysis of Sea Water.—The principal substance which is held in solution by sea water is chloride of sodium, or common salt. The following may be taken as a fair analysis of sea water: Out of every hundred parts of solid matter in sea water

```
 72 parts are sodic chloride
 11  ,,    ,,  magnesic chloride
  6  ,,    ,,  magnesic sulphate
  5  ,,    ,,  calcic sulphate
  2  ,,    ,,  calcic carbonate
  4  ,,    ,,  organic and other unimportant substances.
─────
100
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The substances most injurious to a marine boiler in the above, are the calcic sulphate and calcic carbonate, the second forms solid incrustations on the boiler, while the other eats it away. The amount of salt, it is seen, is 72 parts out of one hundred. Again, if thirty gallons of sea water be taken and evaporated, the residuum will be a gallon of salt; so that when we consider the large amount of water used by an engine, we can soon form an idea of the quantity of salt, etc., left behind, and how quickly danger may ensue through carelessness or want of proper precautions.

31. Point of Saturation.—It has been a problem for

the solution of marine engineers how to best get rid of these impurities, especially the salt sodic chloride, as it is present in the largest quantities. The only effectual method of disposing of the salt is not to let the water in the boiler become too salt. This is done by opening a communication, called the blow-out valve, between the boiler and the sea, and letting the water run from the boiler into the sea, and then filling up the boiler with fresh sea water. Sea water contains $\frac{1}{30}$ of salt, etc. Suppose we have a boiler containing a thousand gallons of salt water, and one half, or 500 gallons, is evaporated, it is evident that the remainder will contain double the original quantity of salt, or $\frac{2}{30}$. If one half of this be evaporated, so as to leave only 250 gallons, these will contain $\frac{4}{30}$ of salt, after which, if no feed enter the boiler, the water will soon reach what is called the point of saturation, $\frac{11}{30}$, and the salt in the water will fall down, for the water is *saturated* with salt, or will hold no more. The usual practice is never to allow the salt in the boiler to exceed $\frac{4}{30}$, or to blow out from the boiler *one-third* the quantity evaporated. If 300 cubic feet are evaporated, another hundred must be blown out, or as the 300 + 100 must be equal to the total amount of feed water, of the latter one quarter must be blown out. It may be illustrated thus: Of every 100 gallons or cubic feet of water that enter a marine boiler, 75 may be turned into steam, and the remainder blown out of the boiler into the sea. Such a practice will prevent the boiler water exceeding $\frac{4}{30}$ of saltness.

32. Brining the Boiler.—The process of blowing the brine out of the boiler is frequently called "brining the boiler." It is a custom to blow out at certain given periods, or after the engine has been at work, every 3 or 4 hours; but it is evident that if we have intelligent men driving our engines, they ought, by examining the water, or by calculating how much feed they have used, to know better than to depend upon such a rule of thumb method when to brine the boiler.

33. Incrustation of Land Boiler. — Land boilers become incrusted by the deposition of lime, iron, and other injurious substances upon the inside of the boiler. Just as we see a kettle incrusted by "fur," so land boilers are liable to the same thing, but to a much greater extent. Water from off the oolite, chalk, and other formations containing lime always incrusts boilers.

34. To Prevent Scale Forming in Boilers.—It has already been shown how this is accomplished in marine boilers. In land boilers nothing will prevent the formation of scale but the use of absolutely clean water. Many empirical receipts are given, but the most they do is to throw down the substances held in solution in the form of powder, which is simply a change of evils without any compensating advantage.

35. To Clean Scale from a Boiler.—This should always be done with the chipping chisel. It is condemned by many engineers as a vicious and bad custom, to throw a few shavings into the boiler, which, by creating sudden heat when set on fire, causes the inside shell of the boiler rapidly to expand, and thus separate itself from the incrustation.

36. Danger of Scale.—This will be fully treated under the head of boiler explosions.

37. High Pressure Steam Does not Scald.—If steam at high pressure be issuing from an orifice and the hand be placed in it, it will not be scalded. The reason must be that, as it issues into the air, the pressure is decreased and reduced to 15 lbs. The steam, therefore, immediately takes to itself the deficient latent heat from the air; for the latent heat of high pressure steam is less than that of low pressure, and as steam, when it has issued into the atmosphere, is under a pressure of only 15 lbs. on the square inch, it must necessarily take to itself the required amount of latent heat for that pressure. If the pressure had been 30 lbs., the deficient latent heat would have been 22°C. The steam is, therefore, busily employed in taking these 22° of heat from the atmosphere, and even

from the hand placed in it; and so, under the circumstances, will rather cool than scald the hand.

38. Measure of the Pressure of Steam.—The pressure of steam is measured by atmospheres. Steam of 15 lbs. pressure is steam of one atmosphere, of 30 lbs. pressure of two atmospheres, etc. It is frequently used as high as six or seven atmospheres; but even ten, or 150 lbs. pressure, is employed. Steam below two atmospheres is termed *low pressure steam*, and all pressures above, *high pressure steam*. This is one of the points, and really of no consequence, upon which scientific men have no uniform opinion; what some consider high pressure, others consider low or ordinary pressure steam, while some term steam above one atmosphere high pressure. It is better, in the unsettled state of opinion, to make no distinction, as above, between high and low pressure steam, but simply state that you are using steam of one, two, three, or more atmospheres.

39. Superheated or Surcharged Steam.—It has become a practice to allow the steam, before it enters the cylinder, to pass from the boiler into a series of tubes, or into a strong iron chamber in which a large quantity of vertical or horizontal tubes are fitted; in these the steam is further heated to increase its elasticity by the heat that is passing away up the funnel or stack, thus from a given quantity of steam a maximum amount of work is obtained with a minimum amount of fuel consumed. A simple method of superheating steam is to allow it to pass from the boiler by means of a short pipe into a small chamber round the bottom of the funnel, and thence let it pass to the engine.

40. The Advantage of Superheated Steam is, that as we increase the pressure the amount of work done by the engine rapidly increases also; but the quantity of heat contained in high pressure steam is very little more than in low pressure. For instance, the units of heat in steam at $110°$C., pressure of $21\frac{1}{4}$ pounds, is $= 640°$C., at $165°\frac{5}{9}$C., or 104 pounds pressure, it is $657°\frac{2}{9}$C., or only $17°$C. more.

Since it is heated by the waste products of combustion passing up the funnel or stack, it is more economical than ordinary steam, but it is by no means economical if this heating is carried to excess. To ensure efficiency it wants little more than drying.

In consequence of its great heat, superheated steam does injury to the internal parts of the engine; it burns the packing, and eats away the cylinders, especially having an injurious effect upon those of indifferent workmanship. As steam is superheated so its elasticity is increased, or the elasticity varies with the temperature. In practice many engineers do little more than dry the steam; for this purpose a small chest, or outer casing, is sometimes fitted round the bottom of the funnel, the steam passes through a short pipe from the boiler to this casing, and is then led away to the cylinder to do its work.

41. Steam when in Contact and not in Contact with the Water.—Remembering the large amount of latent heat in steam, it is evident that the steam contains much more heat than the water from which it is produced. When steam is generated in a boiler and not allowed to escape, as fresh quantities rise from the water the *density* and *elasticity* of the steam must increase; at the same time the boiler is receiving fresh additions of heat. So then, as the temperature increases so do the density and elasticity, which arises from two causes; first, the expansive property of the steam, second, the continual additions of fresh steam keep continually increasing the density and elasticity, while the fire increases the temperature to correspond with the pressure. Steam under such a condition as this is said to be *saturated*, that is, it contains as much vapour as it possibly can for its temperature.

As long as the steam remains in contact with the boiler water, the pressure exhibited by the gauge always corresponds to a certain temperature, and the same temperature in the boiler will always correspond to the same pressure of steam. If the steam be taken from the boiler

and further heated in another vessel, in which is no water, we may increase its pressure or elasticity, by increasing the temperature, to almost any extent; but, by doing this, we decrease its density, hence the great distinction between steam when in contact and not in contact with the water is this: when in contact with the water there is a constant ratio between pressure and temperature, but the invariable connection between pressure and temperature does not exist when the steam is not in contact with the water. We may increase the one without augmenting the other.

42. Specific Gravity of Steam.—The specific gravity of steam is its weight compared with an equal volume of air. The specific gravity of steam is ·481, or less than half the weight of the same volume of air.

43. Quantity of Water Required to Condense Steam. —Already it has been shown that the latent heat of steam is nearly five and a half times as much as the sensible heat. Suppose, for instance, we place in an evaporating dish a certain quantity of water, two, three, or four ounces, at a temperature of 22°C., to it we apply the flame of a spirit-lamp, and it boils in $3\frac{1}{4}$ minutes, and continuing the same amount of heat we find the whole is evaporated when 22 minutes 23 seconds more have elapsed. Let us see what we can gather from this:

The water is raised from 22° to 100°, or through $100° - 22° = 78°$ of heat in $3\frac{1}{4}$ minutes; therefore we conclude that every $3\frac{1}{4}$ minutes heat sufficient to increase the temperature 78° will pass into the water. Into 22 minutes 23 seconds the $3\frac{1}{4}$ minutes will go $(22\frac{23}{60} \div 3\frac{1}{4} =)$ 6·887, therefore the total heat passing in after it begins to boil is $6·887 \times 78° = 537°·186$ C. From this we learn that to evaporate the water takes very much more heat than to boil it, and that the latent heat of steam is 537°·2 C. Again, when this steam returns to water it gives up all its latent heat. We have now to inquire what amount of water is sufficient to reduce this steam immediately to water.

Watt came to the conclusion that $22\frac{1}{4}$ cubic inches of water would condense a cubic foot of steam, or the steam formed from one cubic inch of water, if every atom of water did all it was capable of doing. He reasoned somewhat in this way:—Suppose the latent heat of steam is $537°·2$ C., the temperature of the hot well being $37°$ C., and that of the condensing water $10°$ C., therefore every atom of water will have its temperature raised $37° - 10° = 27°$ C., and as there will be left in the steam converted into water $37°$, the cold water has to take up $637°·2 - 37° = 600°·2$ C.; therefore the total cubic inches of water required for condensation $= \frac{600·2}{27} = 22·23$, or $22\frac{1}{4}$ inches. But as every particle of the water cannot be made to do all its work, he allowed for condensation $28·9$ cubic inches, or a wine pint for each cubic inch evaporated in the boiler, or, in practice, he allowed about one quarter more than was *theoretically* necessary.

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EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. State clearly the difference between vapour and steam.
2. On what does the boiling point of water depend? State the ordinary temperatures at which fresh and sea water boil respectively. What influences the temperature at which sea water boils.
3. What is high pressure steam? and explain fully the meaning of the expression, "He is using steam of *three atmospheres.*"
4. What difference is there between steam in contact and not in contact with the water from which it is generated? What is Mariotte's law?
5. What relation exists between the pressure, density, and temperature of steam?
6. Give the numerical value for the specific gravity of steam. Compare its weight with one or two other gases or fluids.
7. How is steam superheated? What is the difference between common and superheated steam?
8. Of what does sea water consist? Give its constituent parts.
9. What weight of injection water at 80°F. will suffice to condense a given quantity of steam into water at 120°F. (1863)?
Ans. 26·4 for each ounce steam.

Each given quantity of water is raised from 80° to 120° or 40°.
The whole heat in the steam is 967° + 180 = 1147°F.

When this is condensed we leave it at a temperature of 120°.

∴ We have to put in the water 1147 – 88.

As each quantity of water takes in 40°.

∴ Total quantity required is $\frac{1059}{40} = 26 \cdot 4$.

10. The temperature of the injection water is 70°F., what quantity of injection water will be required to condense a cubic foot of water turned into steam to a temperature of 150°F. ?
                                                    Ans. 12·86 cubic feet.

11. The hot well is to be kept at a temperature of 125°F., when that of the injection water is 80°F., how much injection water will be required?   *Ans.* 23·42 nearly.

12. The temperature of the injection water is 75°F., and the hot well is kept constantly at 127°F. ; find the quantity of injection water that is being used.   *Ans.* 20·2.

13. Two ounces of water at 60°F. are placed in an evaporating dish, which is covered, except a small opening, by a glass plate. The flame of a gas burner causes the water to boil in 3½ minutes, and the whole is evaporated after 22 minutes more have elapsed. What would you infer as regards the latent heat of steam from this experiment? What is the correct numerical value given by a more exact process (1871) ?

In 3½ min. there pass into the water (212 – 60) = 152°F.

$$
\begin{array}{ccccc}
1 & ,, & ,, & ,, & ,, & \dfrac{152}{3\frac{1}{3}} \\[2mm]
22 & ,, & ,, & ,, & ,, & \dfrac{152 \times 22}{3\frac{1}{3}} = 1003 \cdot 2°F.
\end{array}
$$

We, therefore, infer that the latent heat of steam is 1003°; the more correct value is 967°F.

14. The temperature of the injection water is 60°, the steam enters the condenser at a temperature of 212°, the water pumped out of the condenser is at a temperature of 110°; what weight of injection water must be supplied for each pound of steam which enters the condenser (1870) ?

            (The latent heat of steam at 212° is 966·6).
                                                    Ans. 21·37 lbs.

15. What is meant by superheated steam? What advantages are gained by its use (1865) ?

CHAPTER III.

RADIATION, OXIDATION, Etc.

The Radiation of Heat—The Absorption of Heat—Reciprocity of Radiation and Absorption—Good and Bad Radiators—Experimental Illustrations—Oxidation of Metals—Effects of Galvanic Action.

44. Radiation. — "Radiation is the transfer or communication of heat from the particles of a heated body to the air or ether." It is a transmission of motion; the vibrations of the heated body, being communicated to the air, sets it in motion. This motion is called *radiant heat.*

45. Absorption. — Absorption is the transmission of motion (radiant heat) from the ether to the particles of any body. Thus when a body is placed in the path of a beam of radiant heat, it partakes of its vibrations, and is set in motion, *i.e.,* it becomes warm, or absorbs the motion.

46. Good and Bad Radiators.—All bodies have not the same powers of radiating and absorbing the motion of heat. Bodies possessing these powers in a comparatively high degree, are said to be *good* radiators and absorbers, and those possessing them in a less degree *bad* radiators or absorbers. Thus earths are good, and water and metals bad radiators. Smooth polished surfaces radiate and absorb much less heat than rough or dirty surfaces. Cylinder covers should be kept perfectly bright, so should teapots and kettles, except the bottoms of the latter, which are required to be good absorbers. A stove for cooking should be bright, while a stove or pipe for heating a

room or greenhouse should be rough from the casting mould, and not painted. Radiation can be prevented by clothing with non-conductors. Cylinders have a wooden casing made for them; boilers are built into brickwork with layers of ashes, sawdust, etc., around them; and steam pipes are covered with matting, etc., to prevent radiation.

47. Reciprocity of Radiation and Absorption. — It is interesting to note the reciprocity which exists between the power of a body to communicate the motion of heat to the ether, *i.e., to radiate*, and its power to receive motion from a heated body through the medium of the ether, or to absorb. In other words, *good radiators are good absorbers*, and *vice versa*. Thus the earth (rocks, etc.) quickly absorbs the radiant heat of the sun, but no sooner does the sun set than the heat radiates from it; while the sea slowly gets warm, and retains its heat much longer than the earth.

48. Experimental Illustrations — *Radiation.*—Place a common mercurial or other thermometer about a yard distant from the fire, or any other heated body, and instantly it will indicate an increase of temperature, the motion having been communicated by the fire to the air, and by *absorption* it has been accepted or absorbed by the glass of the thermometer, and by conduction transmitted to the mercury. The melting of ice when placed before the fire, warming your hands, the sun heating the rocks, and they in their turn warming the air, are all instances of radiation from the heating body and absorption in the body warmed.

Good and Bad Radiators.—Take two hollow vessels, one of metal and one of earthenware, and fill them with boiling water. If a thermometer be held outside and close to the metal one, it will be found to show a much less increase of heat than when placed outside and close to the earthenware vessel, and the water in the earthenware vessel will cool much more rapidly than that in the metal one. As a rule metals are bad radiators, and earths good radiators. A slate held before a fire

will receive or absorb much more heat than a brass plate, and so on.   Dry atmospheric air will absorb no heat whatever; in fact, the rays of the sun, or radiant heat from artificial sources, may pass through it without altering its temperature.   On high mountains the direct rays of the sun may be almost unbearably scorching, while the air is perfectly cold, and the traveller has only to withdraw into the shade to feel the freezing chill of the atmosphere.   For the same reason, that the air is perfectly dry, ice is often formed at night in the desert of Sahara, where, during the day, the direct rays of the sun make it a fiery furnace.

Reciprocity of Radiation and Absorption.—If when a red hot ball be placed between two plates of pewter and glass respectively, and the different temperatures of the two plates and of the air immediately around them be noticed, it will be seen that the glass not only receives or absorbs much more heat than the pewter, but also that the radiation from the glass is much more powerful than from the pewter.

From the remarks accompanying the definition of reciprocity of radiation and absorption, it will be seen that where radiation is powerful we may expect good absorption, and *vice versa.*

49. Galvanic Action and Oxidation of Metals. — Metals are subject to two kinds of deterioration — galvanic action and oxidation.   When two different metals come in contact, especially if they are constantly wet, a galvanic current is induced which results in the decomposition of one of the metals, or one destroys the other. For instance, who has not observed that old iron railings are frequently wasted away towards the bottom, close against the lead that fastens them into the stone?   The reason is, that a galvanic current passes from one to the other, and the soft lead wastes away the hard iron.   If we take, in the following order, silver, copper, tin, lead, iron, and zinc, we have these in their relative positions as regards galvanic action, and the farther they are from

one another in this list the greater the effects of galvanic action. Those coming first in order will destroy any that follow them. Copper, when in contact with tin, lead, iron, zinc, etc., will waste them away, but not silver— the silver will eat away the copper, tin, lead, etc. When copper pipes are fastened by iron bolts or screws, the iron is soon destroyed, especially in damp situations.

Oxidation is a chemical action. When iron rusts we have an instance of oxidation. The oxygen of the air enters into chemical combination with the iron, and forms oxide of iron or rust. When the oxygen of the air combines with the copper, we have oxide of copper or verdigris. Zinc in the same way becomes covered with a layer of the oxide of that metal when exposed to the air. Thus it is necessary that metallic substances should be covered with paint, grease, etc., when exposed to the air, or otherwise oxidation may proceed with sufficient rapidity to injure them.

Two other facts, which are closely allied to oxidation and galvanic action, may be stated, namely :—when superheated steam is employed in jacketed cylinders, and much tallow introduced, it is found that the tallow is decomposed, and *carbonises* the piston, so that it becomes more like a piece of plumbago than anything else. Cast iron long immersed in sea water may be cut with a knife.

CHAPTER IV.

THE ENGINE BEFORE WATT, AND WATT'S ENGINE AND IMPROVEMENTS.

Savary's Engine—Newcomen's Atmospheric Pumping Engine—
Its Defects—The Discoveries of Watt—The Separate Con-
denser—The Expansive Working of Steam—Its Economy—
Its Value in Regulating the Power of an Engine—Details
connected with Watt's Single Acting Pumping Engine—
The Steam Cylinder—Valves connected with Cylinder and
their Action—The Condenser—The Air Pump—The Foot
Valve—The Delivery Valve—The Snifting Valve—The Hot
Well—The Piston-Rod—Connecting Rod and Crank—Stuff-
ing Boxes and Glands—Parallel Motion—Method of Starting
the Engine and of Regulating its Speed by the Governor—
The Throttle Valve—The Cataract—Eccentric.

50. Savary's Engine.—Savary's was the first steam
engine employed to pump water. He took out his patent
in 1698. His engine consisted of a cylinder, in which
steam was employed to produce a vacuum only, after
which he relied upon the pressure of the atmosphere to
raise the water. At the top of his cylinder were two
openings, each fitted with a pipe and a stop-cock. These
were so arranged that the same handle opened one stop-
cock and shut the other simultaneously. One pipe
communicated with a boiler and admitted steam to the
cylinder, the other with a cistern of cold water. From
the bottom of the cylinder a pipe led down to the water.
It acted thus: Suppose the handle of the stop-cock
moved, and steam admitted to the cylinder, directly it
was filled the handle was pushed back, and a dash of water
from the other cock condensed the steam and formed a
vacuum; then the pressure of the air on the water at the

bottom of the mine forced the water up into the cylinder, which was prevented from returning by a valve opening upwards; on a second admission of steam, its elastic force acting on the water drove it through a valve in the side of the cylinder opening outwards; this steam was again condensed as before, etc. We thus see the principle upon which it acted. The water was first forced by atmospheric pressure into a vacuum, after which the elasticity of the steam, pressing upon its surface, was made to raise it still higher through another passage. The inefficiency of this machine is apparent. Its defects were: that steam was used in a cold cylinder; that the steam was always in contact with cold water, and, therefore, the greater part of it was lost ; that the engine was limited in its range and purpose; that it must be always far down in the mine from which the water was raised.

51. Newcomen's Engine.—Thomas Newcomen was a Devonshire man, and the first to work out the idea of a piston (at least in England). His engine was used for pumping. In fact, the one idea of the early labourers at the steam engine was to adapt it, or to invent a machine, to pump water out of the Cornish mines.

Newcomen placed his cylinder immediately above his boiler, from which steam passed directly through a stop-cock. As soon as the piston was at the top of its stroke, a cock was opened and cold water admitted into the cylinder to condense the steam; a vacuum being thus obtained, the pressure of the air, 15 lbs. on the square inch, immediately drove down the piston, which was attached by a chain to the end of a sway beam moving on its centre. The piston being thus forced down by atmospheric pressure pulled up the other end of the beam at the same time, and with it the pump rods, water, etc. When fresh steam was admitted it forced up the piston against the atmosphere, while the weight of the pump rods, etc., at the other end, assisted the steam. The weight of the pump rods, etc., was generally made equal to half the

pressure of the air on the piston. This engine raised 7 or 8 lbs. for each square inch of the piston. Newcomen's was a *single acting* engine, because the steam acted on one side of the piston only.

In Newcomen's engine, as represented in the accompanying figure, A P is the ashpit, F P the fireplace, B the boiler, S C a stop-cock to admit the steam into the cylinder H from the boiler B. The cylinder was bored as truly as possible, open at the top and closed at the bottom, being connected with the boiler by a short pipe containing the steam-cock. A piston p was made to move up and down in the cylinder, as air-tight as practicable, by packing its edges with hemp and covering the upper surface with water. The piston-rod r was attached by a chain c to the circular arc c d, forming the end of the beam e C d, *which was now for the first time introduced.* The beam worked on its centre C, and was formed of strong
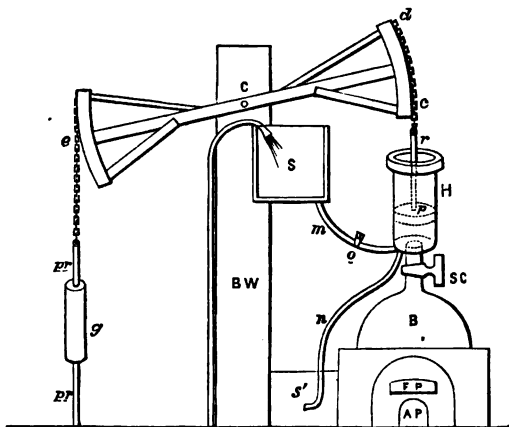
NEWCOMEN'S ENGINE.

timbers firmly put together and strengthened by iron bars and straps. The whole beam was supported on a strong brick wall, B W. To the chain e attached to the

other arc was fastened the rod *p r* of the pump to be
worked in the mine. The power of the engine was in
the down stroke. The pump rod was made heavy enough
to act as a counterpoise by attaching weights *g* to it, so
that it was heavier than the piston, piston-rod, friction,
etc. When the cock S C was opened and *air* admitted,
it would rise freely without violently jerking out the
piston *p*. A safety valve was placed on the top of the
boiler. The manner in which the engine worked may be
thus described :—

The boiler B was filled with a proper quantity of water,
and the steam "got up" to a pressure a little above that
of the atmosphere. The cock S C was opened (supposing
the piston at the bottom of the cylinder), and the steam
entered the cylinder, when the piston ascended partly
through the force of the steam, but chiefly in obedience
to the counterpoise weights *g*. Just before the piston
reached the top of the cylinder, the steam-cock was shut
and another cock *o* opened, which allowed water from
the cistern S to flow through the pipe *m* and condense the
steam in the cylinder, producing a vacuum, when the
pressure of the external air, acting on the top of the
piston, caused it to descend with a force proportionate
to its area; and as this force amounts to nearly 15
lbs. on the superficial inch, it was fully competent to
raise the end of the beam *e*, and with it the pump rods
and water. We thus see that the real work was done
by the *atmosphere*, and why it was called an atmospheric
engine. All the 15 lbs. was not effective.

Originally, it was much less perfect than here de-
scribed, for the condensation was in the first instance
performed from the outside of the cylinder. The admis-
sion of water into the cylinder to condense the steam was
discovered accidentally, through some holes being in the
piston of an engine which permitted the water, placed
upon it to keep it air-tight, to run through and condense
the steam, although we must remember Savary had in-
troduced steam into his cylinder and *condensed it in the*

cylinder. The great difficulty of opening the cocks at the proper moment was conquered by Humphrey Potter,* who attached some strings and catches to the cocks of an engine he was employed to work at Wolverhampton, in order to release himself from the trouble of attending them; his contrivance gave the first idea of "hand gear." The greatest nicety and attention on the part of the workman was necessary in turning the two cocks at the proper moment; for if steam were permitted to enter the cylinder for too great a length of time, the piston would be carried out of it or blown out of its place; while, on the contrary, if not opened soon enough, it would strike against the bottom with sufficient force to break the cylinder. The steam was liable to become mixed with air which was disengaged from the injection water. This air, together with the injection water, was discharged by a pipe *n* into the cistern *s'*. The pipe *n* terminated in a valve to preserve the vacuum, which valve, from the peculiar noise it made, was called the *snifting valve* or *snifting clack.*

52. Defects of Newcomen's Atmospheric Engine.— We have already hinted that it was named an *atmospheric engine,* because it depended upon the pressure of the atmosphere to perform the down stroke, or to do the real work. Its great defect was that the steam was used in a cold cylinder and condensed in a hot one; *i.e.,* it was cold when required to be warm, and warm when it should be cold. It has been estimated that, by condensing the steam in the cylinder, three-fourths of the power of the engine were lost.

53. The Discoveries of Watt, and Separate Condenser. —Watt, having the model of an atmospheric engine, such as we have just described, to repair, asked himself the question, whether it were not possible to prevent the wasteful expenditure of steam. He saw intuitively the great defect of the engine, and set himself to solve the problem of a separate condenser. In this he completely

* Millington's *Mechanical Philosophy.*

D

succeeded, and never left the steam engine until it was comparatively a perfect machine. The annexed figure is a fair representation of the *great* improvements he introduced.

A B is a large casting, within which is placed the condenser C, the air pump A P, and the hot well H W. V is the piston or bucket of the air pump, with its two valves shut down, but shown by dotted lines as they will appear when the piston V is descending. E P is the
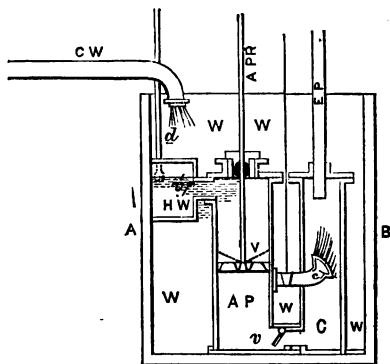
CONDENSER AND AIR PUMP.

exhaust pipe, to convey the used steam from the cylinder into the condenser C. C W is a pipe bringing cold water from the pump, *v* the foot valve, *v'* the delivery valve. W W W W is water surrounding the condenser and air pump, to keep the condenser cold.

Let us suppose that the steam, having been used, comes from the cylinder through the exhaust pipe E P. The moment it enters the condenser, it is met by a scattered jet of cold water from the rose head *c*, and is condensed. The condensed steam and water fall to the bottom of the condenser, and pass or are drawn through the foot valve *v*.

Then the piston or bucket V of the air pump comes down into the water; the pressure of water opens the two butterfly valves, and the water passes through the valves, and so gets above the piston. When the piston is drawn up, the two valves are closed by the weight of the water above them, which is next forced or delivered into the hot well H W, through the delivery valve v', from whence a portion of it is pumped into the boiler through d, a part of the *feed pump*. As the air pump ascends a vacuum is formed in A P, at least as good a vacuum as exists in the condenser C, so that the condensing water passes by gravity, etc., through the foot valve v, or "follows the bucket." As the air pump descends, we see v must close, so must v'; on the contrary, as it ascends, both delivery and foot valve will open.

All water contains air more or less. The heat of the steam disengages the air from the condensing water, which would rise through the exhaust pipe, and prevent the proper escape of steam, and counteract its pressure if not got rid of.

The air pump was, therefore, added by Watt to his invention of the condenser, to prevent air from accumulating and obstructing the engine.

54. The Expansive Working of Steam—its Economy —its Value in Regulating the Power of an Engine.— By expansive working of steam is simply meant this: that the steam from the boiler is admitted to the cylinder during only a part of the stroke; this admission being stopped, the steam in the cylinder has then to complete the remainder of the stroke by its expansive property. By Boyle's or Mariotte's law, the pressure of steam varies inversely as the space it occupies. For instance, suppose we have a cylinder full of steam at a pressure of 30 lbs. on the square inch, if we compress it into one half the space, the pressure will then be 60 lbs. on the square inch; while, if we allow it to fill another cylinder of the same size, as well as the one it originally occupied, or, in other words, allow it to double its volume, its pressure will be only 15 lbs.; *i.e.*, compress it into half the space its pressure is doubled, allow it to occupy twice the space the pressure is only one half.

This figure will give a fair idea of the expansive work-ing of steam, and its economy and value in regulating the power of an engine. Suppose steam of 60 lbs. is admitted to a cylinder 6 ft. long, and cut off at ⅓ the stroke, then
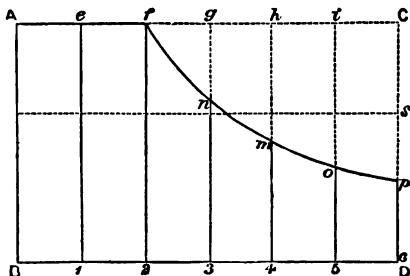
AN EXPANSION DIAGRAM (THEORETICAL.)

during the first and second feet the pressure is 60 lbs.; at the end of the third foot, the steam will occupy one and a half (3/2) the space, the pressure at the end is therefore ⅔ of 60 lbs. = 40 lbs.; at the end of the fourth foot the steam fills twice the space, the pressure is then ½ of 60 lbs. = 30 lbs. So that from the end of the second foot to the end of the fourth the pressure has fallen from 60 lbs. to 30 lbs. At end of the fifth foot the steam fills two and a half (5/2) times the space, hence pressure is ⅖ of 60 lbs. = 24 lbs. Hence we have steam being admitted at 60 lbs., and

<div align="center">

At end of first foot its pressure is 60 lbs.
,,   second ,,   ,,   60   lbs.
,,   third   ,, (⅔ of 60)=40   lbs.
,,   fourth ,, (¼ of 60)=30   lbs.
,,   fifth   ,, (⅖ of 60)=24   lbs.
,,   sixth   ,, (⅓ of 60)=20   lbs.

</div>

We may say that steam of 20 lbs., by giving it a great initial pressure, and cutting it off at one third stroke, has been made to do work equal to steam whose average pressure is above 39 lbs. Again, during the first and

second feet the pressure of steam was $60 + 60 = 120$ lbs., during the remainder of the stroke the pressure $= 40 + 30 + 24 + 20 = 114$ lbs., so that without any additional expenditure of steam, by merely allowing it to expand, we get almost double the work out of it when the steam is cut off at $\frac{1}{3}$ stroke. We nearly double the work of one-third of a cylinder of steam by mere expansion. This sufficiently shows its superior economy. If in our figure we cut off from g $\frac{2}{3}$ of its length, from h $\frac{1}{2}$, from i $\frac{2}{5}$, from C D $\frac{1}{3}$, and through the points draw the curve f n m o p, then that curve will represent the gradually decreasing pressure of steam. It is an hyperbolic curve. We may partly see the reason for the rule to find the units of work done by a piston in one stroke, which is

$$q\,p + q\,p \text{ log.}_{\varepsilon} \frac{l}{q}$$

where q is the portion of the stroke moved through before steam is cut off, l is the length of the stroke, and p the pressure at which steam is admitted. For a proof of this formula the reader is referred to the volume on *Steam* in the Advanced Series.

55. Watt's Single Acting Engine.—In this engine A B is the cylinder, P the piston, P R the piston rod, S the steam pipe, D leads to the exhaust, a b c are three valves on one spindle, a the steam valve, b the equilibrium, and c the exhaust.

The following is an explanation of the action of this engine :—Steam comes along the steam pipe S from the boiler, when the valves a b c, being in the position shown in the figure, with a and c open and b closed, the steam enters the cylinder A B in the direction marked by the arrows with tails, and drives the piston down, causing the pump valves at the other end to ascend. Steam that may have been under the piston in E can freely pass away to the exhaust D. The moment the piston is at the bottom of its stroke, the valves move to

their second position, so that *a* and *c* rest on their seats *o*, while *b* is opened. Then the steam that drove the piston down can run through valve *b*, in the direction shown by the arrows without tails, get under the piston P, and assist in driving it up. The pump rods at the other end are balanced by a counterweight to assist this expanding steam. The action is then continuously repeated : *a* and *c* open, steam enters through *a*, drives down P, and the steam under P escapes through *c*, then *a* and *c* are closed, and steam runs round through *b* to assist the upward motion of the piston.
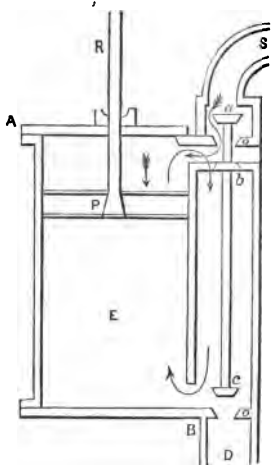
56. Snifting Valve or Snifting Clack was so called from the noise of its action; in Newcomen's engine, page 47, at *s'*, was a valve for the escape of the condensing water and air, through which they escaped from the cylinder with a snifting noise. In Watt's engine a snifting valve was also fitted which communicated with the bottom right hand corner of the condenser, so that the air might escape, but it was chiefly fitted to assist in blowing through previously to starting the engine; the steam admitted by the blow-through valve escaped by the snifting or tail valve, as it is called. A blow valve is not always fitted now, because steam of a much higher pressure is used. Hence neither blow valve or snifting valve are so important as formerly.

57. Double Acting Engines.—When steam drives the piston both up and down, the engine is termed double acting. All our modern engines are double acting ; but

Newcomen's was an atmospheric and single acting engine, the piston being driven up by steam, but down by atmospheric pressure. Watt's first engine was single acting; the steam drove the piston down, while the weight of the rods, etc., at the other end of the beam, brought it up.

58. Clearance.—When a piston makes its stroke it is not allowed to touch the top and bottom of the cylinder for fear of knocking them off.

The space between the top and bottom of the cylinder and the piston, when the latter is at the end of its stroke, is the clearance.

59. Cushioning.—When the steam is shut in before the end of the stroke, the piston acts against it as against a cushion, and so is brought gradually (comparatively speaking) to rest. Suppose the piston is in the position A B when the steam is shut in, and that from A to C is 12 inches. Let us also suppose that the elastic force of the steam remaining behind in A F is 2 lbs., when the piston gets to D, 6 inches down, by Mariotte's law its elastic force will be 4 lbs.; when at E, 9 inches down, it will be 8 lbs., etc. So we see at once the effects and advantages of cushioning, and that it must bring the piston gradually to rest by destroying its momentum.
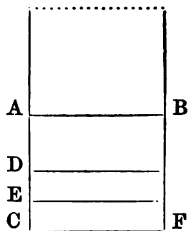
60. The Piston and how Fitted—Packing, etc.—As the piston is a most important part of the engine, great care and thought have been bestowed upon it. It must be perfectly steam tight, and, at the same time, it is required to move easily within the cylinder. A cylindrical piece of iron is chosen and turned about a quarter of an inch smaller in the diameter than the bore of the cylinder, and around it is cut a deep groove square in section; into this is fitted a metallic ring of brass or steel, but generally cast iron; this ring either fits steam tight against the cylinder by its own elasticity, or is forced against it

by springs or compressed air. Formerly "packing" was much used, when some rope yarn was platted the exact size of the square groove, the precise length was cut off, and the ends neatly sewn together—care being taken that no turns were left in the yarn. The whole was well greased before it was fitted in. Metallic piston rings are now most in fashion, the piston being composed of two distinct parts—the piston proper and the junk ring. The junk ring is bolted on to the piston by bolts tapped into the piston and heads recessed into the junk ring. A metal ring is next turned exactly the size of the cylinder, and then cut; when cut, we know such a ring will develop its elasticity, and some force will be required to place the ends in contact again. It thus forms a powerful spring, and is placed between the junk ring and the piston, where a place has been left for it. The piston is now complete, and the spring or metal ring, being compressed into its proper position, the whole is placed within the cylinder, forming a very steam tight easy piston.

Pistons are seldom packed now, but the air pump bucket is; because packing is cheaper, and also because in this case it answers better, for a large amount of galvanic action sets in and eats away the metallic parts of the piston of the air pump.

61. Stuffing Boxes and Glands.—These are used in several parts of an engine. A good example may be seen in the fig. in page 69. The piston-rod enters the cylinder through the stuffing box *s b*; while the packing, the part marked so dark within the stuffing box, is pressed down in its place by the gland *g d*; bolts pass through the flanges of both, so that when the steam leaks through the cover by the side of the piston-rod, we have only to screw the gland down on to the packing, and the leak is stopped by the packing, being forced against the piston-rod. A depression will be seen round the top of the gland close to the piston-rod, it is to hold oil or tallow to lubricate the piston-rod.

62. Method of Starting the Engine.—The engine is

started by opening the stop valve, which allows the steam to run from the boiler to the cylinder; when the steam is in the cylinder it gives the required reciprocating motion to the piston; the supply is regulated by proper openings and valves, to be afterwards explained. In starting an engine, where the single eccentric is fitted, we must notice which way the engine has to go; then with the starting bar move the slide up or down, according to the direction we wish to send the crank, when the piston, etc., will begin to move; a stop on the shaft carries the eccentric with it; when in the proper position, the end is dropped on to a stud or pin and fixed in its place, and the engine itself works the slides. In explaining Stephenson's Link Motion, an effort will be made to render this part of the subject a little clearer.

63. The Parallel Motion.—Although the parallel motion has been almost superseded by simpler pieces of mechanism, such as guides, quite as efficient, yet a description cannot be wholly omitted.

If the end of the piston-rod g had been connected to the end of the beam, the piston-rod would have been bent alternately to right and left as the beam rose and fell, and a continual jarring would be going on, constantly destroying the stuffing box, and rendering the cylinder leaky.

Let us suppose that the simple lines in the adjoining figure represent the parallel motion, C h is half the beam, $h\,g$ is the main link, $c\,d$ the radius bar or bridle rod. As h moves up and down, it describes an arc of a circle with its convexity to the left. Now $c\,d$, the radius bar, moves on its fixed centre c, consequently the point d will describe an arc with convexity to the right; so h throws $g\,h$ to the left, and $c\,d$ throws $d\,e$, and with it $g\,h$, to the right. Therefore it is evident that if these links and rod be proportionately adjusted, we shall have an arrangement that will compel the point g, and with it the whole piston-rod, to move exactly perpendicularly. To accomplish this there are joints at g and d.

To find the proper length of the bridle rod,

Divide C h in e, so that
$$C\,e : c\,d :: d\,o : o\,e$$

where o is the point to which the air pump rod is attached,

$$g\,d \text{ or } h\,e : C\,e : d\,o : o\,e$$
$$\therefore h\,e : C\,e :: C\,e : c\,d$$
$$\therefore c\,d = \frac{C\,e^2}{h\,e}$$
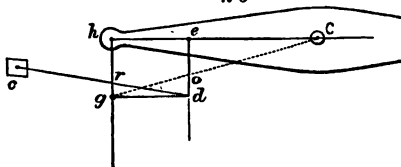
PARALLEL MOTION.

The parallel motion will work most accurately when the radius rod, from c to d, is about the same length as the beam from C to h, they should therefore be kept as nearly equal as circumstances will permit.

64. The Governor.—The governor consists of two balls, A and B, fixed on the ends of two arms, and so arranged that they can freely revolve round the spindle C D. Motion is imparted to the balls either by a pulley, which is driven by a cord passing over another pulley on the main shaft by the side of the fly wheel, or else by a pair of bevel wheels placed immediately below D.

When at rest, the balls will remain close to the governor spindle, as in the figure, but when in motion the faster it moves the farther the balls will fly asunder by centrifugal force. As they separate, the arms A C and B C will extend outwards, and will bring up with them the short arms G H and E F, which will move up the collars I, L. when the arm M N will pull point N to the left; P is a fixed joint and P Q is firmly attached to P N, so that point Q will be lifted up and close the throttle valve V in the steam pipe S, by means of two arms, one of which, Q V, is shown in figure, moving the valve on its spindle. Thus,

the faster or slower the main shaft moves, the faster or slower will the governor move, and close or open the throttle valve and regulate the supply of steam, so that the engine may always be moving at the same velocity.
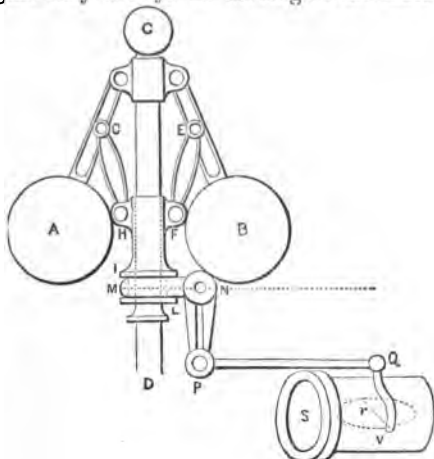
GOVERNOR AND THROTTLE VALVE.

In flying outwards, the balls attain a certain vertical height, which height, and the length of the pendulum, to vibrate in a given time, are calculated, as shown in the volume on *Steam*, in the Advanced Course of this Series. The weight of the balls does not affect the action of the governor at all, for if a heavy ball increases the centripetal force, it also increases the centrifugal in the same ratio. It is called the conical pendulum or pendulum governor, because its motions are regulated by the same laws as those which regulate the ordinary pendulum.

65. Throttle Valve.—From the last figure a good idea can be obtained of the throttle valve. It is a circular or elliptical plate moving on a spindle. Its opening, as regulated by the governor, determines the volume of steam that shall pass to the cylinder.

66. The Cataract.—The cataract supplies the place of the governor in the single acting Cornish pumping engines. It consists of a small pump plunger a and barrel $b c$ set in a cistern of cold water A B; d is a valve opening inwards, so that when the plunger a ascends, the water passes through d from A B into $b c$; f is a cock opened and shut by the plug e, moved by the plug rod g, worked by the beam overhead. If the plunger be forced down, the water will pass through f in proportion to the opening of f. When the beam has moved fully up, it liberates the rod that works the plunger; then as the chamber fills with water through d as the plunger ascends, so when the latter comes down the pressure of water will close d, and the weight of the plunger will force the water through f as rapidly as the opening will allow. The way it is carried away is not shown in the figure. If the cock be shut, the plunger cannot descend; if only slightly opened, it will descend gradually, etc. As soon as a certain quantity of water has passed through f, its weight opens the injection
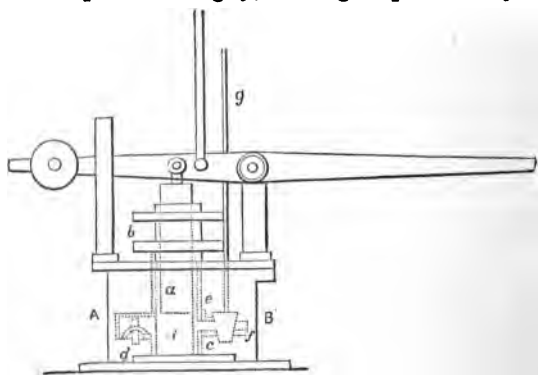
CATARACT.

valve, and condensation takes place, when the engine can complete its stroke; for the engine can only make its stroke as the water is supplied for condensation. It thus

regulates the speed of the engine; for if the cock be fully open, condensation takes place at once, and if only partly open, condensation will be delayed till the water is supplied.

67. **Marine Governor.**—Owing to the unsteady motion of a ship, arising from pitching, rolling, etc., the ordinary pendulum governors are unfitted to regulate the speed of the engines. Mr. Silver has solved the problem how to adapt a governor to a marine engine. He has employed several arrangements for carrying out his ideas. The one of which a section is here shown seems the best adapted to the purpose.

A B is a small fly wheel about 18 inches in diameter, on which are fixed two fliers or vanes, F. The faster the engine goes, the greater resistance will these vanes offer to the air. P is a pulley worked by a cord and fixed on the spindle *s s*, while E is an eccentric and K a lever. To E
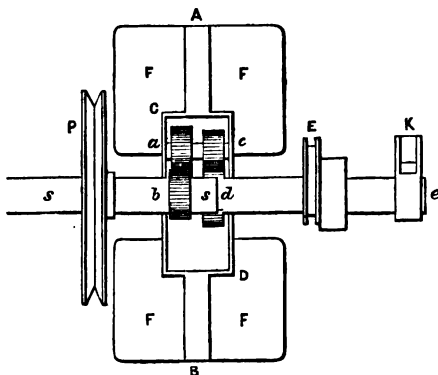
SILVER'S MARINE GOVERNOR.

at the top of the pulley, for the position given in the figure, is affixed a spring. The engineer has to tighten up or slacken this spring according to the speed at which it is intended to drive the engines. K is the lever from which

the motion is conveyed to open or close the throttle valve. Within C D are four pinions to communicate the action necessary to affect the purpose of the contrivance. Sometimes there are six pinions, one below *b* and *d* respectively.

At the uniform speed of the engine, it revolves together in connection with the engine as the motive power; but when accelerated by the running of the engine, as when the screw is out of the water, the increased pressure on the governor fans, or blades, causes the motion to act on the eccentric E, and the lever K carried on the tube *d e*. (We must understand *d e* is not a continuation of *s s*). Then the spring, attached to E or the arm to K, according to whichever arrangement is adopted, acts to close the throttle valve. The pinion *b*, keyed on the solid shaft *s s*, gearing in the wheel *a*, which runs on a loose pin *a c*, transmits the motion to *c* and to *d*, a pinion keyed on the tube *d e*, which acts upon the lever, regulates the speed of the engine. It is excessively sensitive, and the least increase or retardation of speed causes it to act upon the valve. When the pulley is running very fast, the inertia of the fliers and the resistance of the air will not allow the fliers to go as fast as the pulley, so the pinion *a* runs as it were back on *b* (or *b* overtakes *a*), and acting on the spring at E and the lever at K, the latter closes the throttle valve. In one arrangement of this governor, the spring itself works the valve.

68. To Close the Throttle Valve.—To maintain the spring at the elasticity at which it is set requires a certain speed, and when the engine falls below this speed, the spring slackens itself, and allows the valve to open.

69. Eccentric.—The eccentric consists of a disc of metal encircled by a hoop or strap, to which is attached the eccentric rod; in the disc is a hole to pass it on to the main shaft. The centre of the eccentric does not coincide with the centre of the shaft. When the shaft revolves it carries with it the disc, which, moving within the hoop, gives a reciprocating motion to the eccentric rod.

A B is the eccentric, B C the eccentric rod. *a b c* is the solid disc that can move round within the strap or
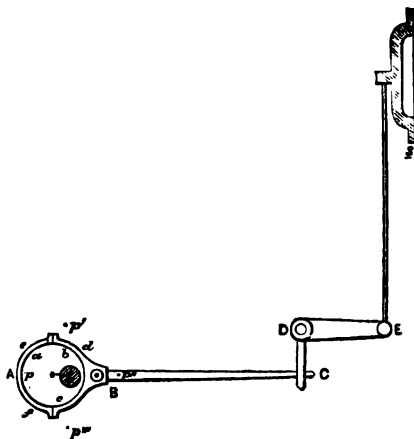
ECCENTRIC, ECCENTRIC ROD AND GEAR.

band *d e f; o* is the centre of the disc. S is the main shaft, on which the disc is tightly keyed. As the eccentric or disc revolves within the strap, it will be easily seen that the point *p,* moving round, will come into the positions *p' p''* and *p''',* and that the point C will be thrown alternately to the right and left. C D E is a bell-crank lever supported on D, a fixed point, and therefore since C moves alternately right and left, E moving along the arc of a circle will give a vertical reciprocating motion, and alternately pull the slide *s* up and down. The distance between the two centres *o* and S (marked by a line in the figure), is called the *throw* of the eccentric. The disc is generally keyed on one-sixteenth of a revolution in advance of being at right angles to the crank.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. Give a description of the steam engine in use before the time of Watt, with an account of his improvements (1863).

2. Give a sketch of a blow valve and a snifting valve, and show why these valves require no springs nor weights to keep them in their seats (1863, 1864).

3. Mention the distinguishing features of the atmospheric single acting and double acting engines, what kind of engine is generally fitted to steam vessels, and what kind is best suited for land carriage (1864).

4. The total pressure on a pair of equal pistons is 90 tons, at the rate of 45 lbs. on each square inch, find their diameter (1866).
Ans. 53·4 inches.

5. Give an account of the steam engine in use before the time of Watt with an account of his improvements (1866).

6. Explain the way in which the eccentrics of marine engines are fixed on the shaft. Explain also the method of obtaining the back motion (1866).

7. The area of a piston is 4876·84 square inches, find the diameter of the air pump, which is half that of the cylinder ; find also the capacity of the pump, supposing it similar to the cylinder (1867). *Ans.* 39·399 and 1219·21.

8. The area of a piston is 4476 square inches, and the diameter of the piston-rod is ⅕th that of the piston, find it (1868).
Ans. 9·43.

9. What is the foot valve ? Is it a necessary appendage to a steam engine. If it is not used, what arrangements must be made in consequence (1867)?

10. The pressure of steam is 15 lbs. on the square inch, and that of the uncondensed vapour is 2 lbs. Compare the effective force in the up and down stroke respectively (1868).
Ans. 16:15.

11. Describe generally the improvements introduced by Watt into the steam engine (1868).

12. What are the foot valve and delivery valve ? What is meant by blowing through ? How is it effected (1868) ?

13. Describe Newcomen's atmospheric pumping engine, and point out its defects (1869).

14. Explain the manner in which the steam acts in Watt's single acting pumping engine. Why is this engine so much more economical in steam than the old atmospheric engine (1870)?

15. Why is it economical to cut off the steam before the piston has gone to the end of the cylinder ? The length of the stroke of an engine is 8 feet, the pressure of the steam on entering the cylinder is 30 lbs. on the inch ; at what point should the steam be cut off so that the pressure at the end of the stroke may be 5 lbs. per inch (1870)?
Ans. ⅙.

16. Describe the eccentric for working the slide valve of a steam engine. How is it thrown in and out of gear? How is it attached to the slide rod in an oscillating engine (1870)?

17. In what manner is the work done by steam estimated? What is the numerical expression for the work done when steam, at an effective pressure of 20 lbs. on the square inch, forces a piston 20 inches in diameter through a space of two feet against a resistance (1871)?   *Ans.* 12566·4 units.

18. It was stated by Watt that neither water nor any other substance colder than steam should be allowed to enter or touch the steam cylinder during the working of an engine. Show that this rule was not adopted in the case of the atmospheric engine, and describe the arrangements by which Watt gave effect to it (1871)?

19. What is done by the air pump in a steam engine? What are the foot and delivery valves, and where are they placed? Describe some gauge for estimating the exact pressure of the air, or uncondensed vapour in the condenser (1871)?

20. Explain the action of the governor and throttle valve in regulating the speed of an engine (1869).

21. Describe the arrangement of the condenser and air pump of a condensing engine, and the valves connected therewith.

E

CHAPTER V.

BEAM ENGINE AND DETAILS.

Double Acting Condensing Beam Engine—Principle upon which it Works, etc.—Details of the Various Parts—Cylinder—How Constructed—Ports or Openings into the Cylinder, etc.—The Form of Slide Valve in Common Use—The Locomotive or Three-Ported Valve—The Lap on a Valve—The Eccentric—The Lead of a Valve—Cushioning the Steam—Clearance—Details of the Piston—Metallic Packing-Rings—The Expansion Valve and the Gear connected with it—The Supply of Water for Condensation—Blowing-through—Gauges for the Condenser—The Barometer Gauge—Method of Estimating Pressure by it—Errors in this Method, and correction of the Same—The Fly Wheel—The Principle of an Equilibrium Valve—The Double Beat Valve—The Crown Valve—The Throttle Valve—The Gridiron Valve—The High Pressure Engine without Condensation — The Expansive Principle as Applied in the Double Cylinder Condensing Engine.

70. **Definition.**—A *double acting engine* is one in which the piston is driven both up and down, or backwards and forwards, by the action of the steam. A *condensing engine* is one in which the steam, after it has driven the piston up or down, is led away to a separate place, where it is condensed by the application of cold water to it. A *non-condensing* engine is one in which the steam, after it has driven the piston up or down, is allowed to escape into the air, and is not condensed, as the locomotive. Non-condensing engines are misnamed high pressure engines, while condensing engines are erroneously termed "low pressure" engines. Non-condensing or low pressure engines were so named because Watt at first used steam but little above atmospheric pressure, and in some cases

even below 15 lbs; while, on the contrary, when steam began to be used without condensation, being necessarily much above the pressure of the atmosphere, such engines were called "high pressure." But now steam of as great a pressure is used in condensing as in con-condensing. Hence it is better to divide engines into the two classes, (1) condensing, (2) non-condensing.

71. Beam Engines.—Newcomen's was a beam engine and so was Watt's, but the latter was far more perfect than the former. The crank was not patented in time by Watt, he therefore used the sun and planet wheel for a crank. The beam was so advantageous and so thoroughly incorporated in the steam engine, that to early engineers it seemed an inseparable part of it as much as the cylinder and piston; therefore when it came to be adapted to marine propulsion, the side lever was the only modification that presented itself. The great advantage of the beam engine is, that to the parts requiring it, it gives a longer leverage, and therefore greater power; a long connecting rod is employed, and thus an immense advantage is gained. Again, a fly wheel was used with it to accumulate power.
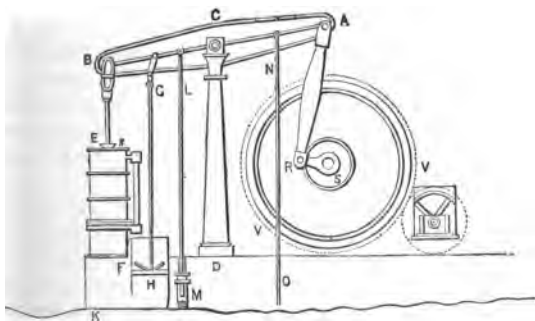
BEAM ENGINE.

A B is the *beam* moving on its main centre C, sup-

ported by a frame and pillars, of which C D is a front one; B E is the *piston-rod* working in and out of the *stuffing box s*, at the top of the *cylinder* E F; G H is the *air pump rod;* H the *air pump*, with the *condenser* H K (only part of which is shown); L M is the *feed pump rod;* M the *feed pump*, into which the plunger is seen descending; N O is *the pump* to force up water for condensation; A R is the *connecting rod;* R S the crank; S the main shaft, on which is firmly fixed the *fly wheel* V V.

The above are the essential parts of the engine, each of which shall be described in detail as far as necessary. The other parts are the *governor*, to open and shut the *throttle valve* in the *steam pipe*, the *slide* and slide casing, the starting gear, the parallel motion, the eccentric, etc.

(1) **The Beam** is a lever of the first kind, and needs no description after an examination of the figure. The power is conveyed into the cylinder which moves the piston, the weight is the force conveyed by the crank, the fulcrum is the main centre.

(2) The piston, the cylinder, the air pump, condenser, and stuffing box have been already described.

(3) **The Feed Pump** is a force pump with a plunger to force the water into the boiler.

A is a solid plunger; *v, v'* and *v″*, are three valves; *b v″* is the pipe that brings the water to the feed pump; *c o* carries away the waste; C *c* leads to the boiler, while *c* is a cock to shut off the feed from the boiler.

FEED PUMP.
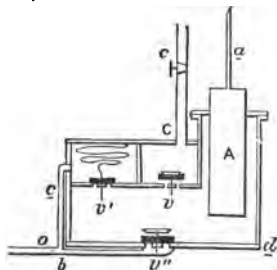
It acts thus. let us suppose the plunger is raised up, then a vacuum is left in the valve box *c d*, therefore water rises through the suction valve *v″*. Let us suppose *c d* is filled, then the descent of the plunger will force the water through the

delivery valve v, and up the pipe C c to the boiler.   But suppose the cock c should be closed, then the great pressure of water will force back the strong spring and open the valve v', so that the water can pass down c o.   Sometimes, instead of this arrangement for the waste water, the pump rod is disconnected when no feed is wanted, and thus the power necessary to work the pump is saved.

(4) The Pump is an ordinary pump for raising water.

(5) The Connecting Rod and Crank have been already partially described. They are used for converting a rectilinear into a circular motion. The connecting rod should be as long as possible; it is generally from three and a half to four times the length of the stroke, but when cramped for room, or otherwise, a much shorter rod is made sufficient.   The longer the connecting rod the greater its advantage. It has more leverage, and therefore does more work.   A short connecting rod gives much pressure upon the guides
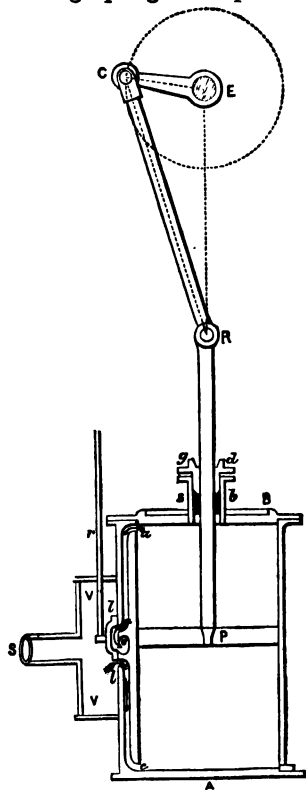
CYLINDER, CONNECTING ROD, AND CRANK.

and a great strain on the crank and crank pin, but with a long connecting rod this pressure and strain are avoided.

With a short connecting rod it is difficult to properly adjust the cut off.

72. Cylinder and Crank.—The figure on previous page is a representation of a cylinder with a locomotive or three-ported slide. Cylinders are constructed of cast iron, and bored with the nicest precision. They must be perfect cylinders, the same diameter from end to end.

A B is the cylinder, P the piston, and P R the piston-rod; C E the crank, and E a section of the main shaft turned by the crank, and connecting rod C R; s b is the stuffing box, and g d the gland; l l is the slide, and r the slide rod by which the engine moves the slide up and down; S is the end of the steam pipe which brings the steam from the boiler to the cylinder; a is the upper port, c the lower port, e is the exhaust port by which the steam escapes from the cylinder to the condenser after it has done its work.

73. How the Engine is Worked.—Suppose the slide is in the position shown in the figure, and that steam fills the valve chamber V V, through the steam pipe S. Now, it cannot pass the back of the slide into the upper port a, because the slide is covering it over; neither, for the same reason, can it pass to the exhaust e; but it can pass into the lower port c, in the direction of the arrows, and drive up the piston P, while, as the piston goes up, the steam that drove it down and filled the cylinder on the upper side above the piston is escaping freely through a, in the direction of the arrows, and passing off to the condenser through e the exhaust port.

When the piston has arrived at the upper end of the cylinder, or at the top of its stroke, the slide l l has moved down lower, so that the lower port c is closed against the admission of steam, and the upper one a opened; therefore steam will enter the upper port and escape at the lower, in a contrary direction to the arrows, the piston returning to the bottom of the cylinder.

74. Slides.—The *locomotive slide* has been already partially described, when speaking of the beam engine

and the way the steam is admitted to the cylinder. The various slides used are the long D, short D, Seaward's, cylindrical, gridiron, etc.
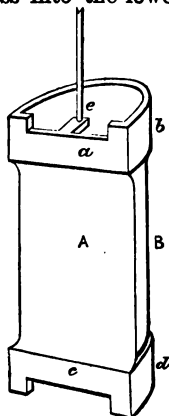
75. The Locomotive Slide is represented in the annexed figure, in which the dark shaded parts are the slide, and the ports are marked *port*. *c* leads to the condenser. The whole of the drawing is covered over by the slide casing, and steam is brought to the back of the slide at A by the steam pipe (not shown). When the steam is acting, it is clearly seen that it presses with great force against the back of the slide at A. The valve rod is shown attached to the back of the slide. When in the position as given in the figure, it is quite evident no steam can pass into the ports and go to the cylinder, as they are both covered over ; but when the slide rod moves the valve up, the steam can pass into the lower port, and drive the piston up, while the steam that is in the upper part of the cylinder can come out at the upper port, when the form of the slide compels it to pass into *b b'* and through *c*, which leads to the exhaust, hence *c* is called the exhaust port. When the slide comes down again, both ports are first closed, then the upper one is open to steam and the lower one to the exhaust, precisely the reverse of the first case. As there are three ports, two steam ports and the exhaust port, this valve is sometimes called the " three ported slide."

76. The Long D Slide is so called

LOCOMOTIVE SLIDE.

LONG D SLIDE.

because its cross section forms the letter D. The two faces, *a* and *c*, fit against the ports. The body, or waist, A B, is smaller than the parts *a b* and *c d*. The steam comes along the steam pipe, and can pass freely round the waist of the valve, and pressing against both back and front it is almost an equilibrium valve. The steam cannot pass by *b, d* nor *a, c*, because the two former parts fit closely to the slide casing, and the two latter press against the ports; only when the valve A is lifted or depressed can the steam enter the cylinder from round the valve. When the steam comes out of the upper port it passes right down the slide at *e* to the exhaust. This is the peculiarity of the slide, that the exhaust passage from the upper port is through the valve.

77. **Short D Slide** may be described as consisting of the upper and lower portions *a* and *c* of the long D, but the passage is closed, and they are joined together by a rod. The steam is still brought to the waist, but cannot pass either *a b* or *c d*, unless the slide be lifted up. Its action is somewhat similar to that of the long D, excepting that the way to the exhaust is not through the slide. There are separate exhaust passages from the top and bottom ports.

78. **Seaward's Slides** were first used by the inventor, after whom they are named. There are four slides, two for the exhaust and two for steam. A is the steam side of the cylinder, and B the exhaust side. When the slides are in the position shown in the figure, the piston is ascending. Steam enters at C; the upper port *a* being closed it cannot enter the top of the cylinder, but it can enter at the lower port *b*, and drive the piston up. As the piston ascends *c* is closed and *d* open, so that the steam which drove the piston down is escaping through *d*. When the piston is descending, *a* and *c* are open, and *b* and *d* closed. D is the way to the exhaust, and B is called the exhaust side of the cylinder; *a* and *b* are termed the induction ports, *c* and *d* the eduction. The slides are kept against the face of the ports by springs, so that any

water that enters the cylinder through priming can easily escape.

79. Cylindrical Slide.— These slides have been introduced and fitted to engines by Maudslay & Field. They are cylindrical in shape. The slide faces are hollowed out concave, and fit on convex nozzles. They are placed between the two cylinders, being used in double cylindered engines, and, when raised, the steam is admitted to the top of the cylinders, and the down stroke follows; and, when depressed, steam enters beneath the piston, and the up stroke is effected.
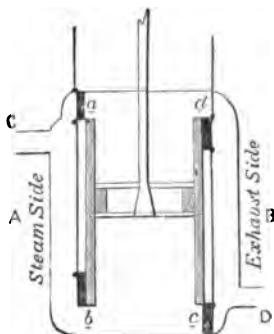
SEAWARD'S SLIDE.

80. The Gridiron Valve.—The gridiron valve is one of the most effective contrivances to give a large opening for steam by a very short movement. Each port is sub-divided into two or more narrow ports, while the valve face has openings to correspond. The principle is the same as that of an air grating in the floor, we have only to give the top plate a slight motion when it is open or shut; the same with this valve, except that the motion is rectilinear and not circular. If A B represent the ports of the cylinder, and the dotted lines the slide face, it is seen that, by simply lowering the slide (face) the smallest amount, the upper ports, A, are immediately open, and the lower, B, closed. When the
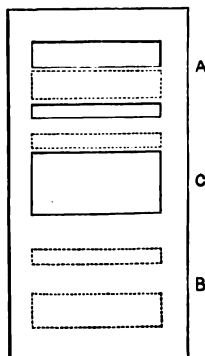
GRIDIRON VALVE.

slide is pushed back, the lower ports will be opened and the upper closed.

Full Steam is the position of the valve when fully open, and the piston is continuing its motion.

Cut-off is the position of the valve when it has just closed the port against the admission of steam.

Angular Advance is the angular measurement of the arc described by the centre of the eccentric while passing from the place it occupies when the valve is at half stroke, to that which it occupies at the commencement of the stroke of the piston.

Linear Advance is the distance which the valve moves while the centre of the eccentric is describing the above angle.
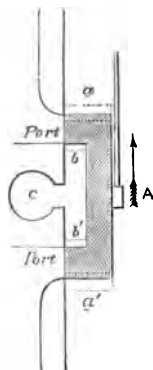
81. Lap and Lead of the Locomotive Slide.—The width of the opening of the steam ports, for the admission or for the release of the steam at the beginning of the stroke, is known as lead. On the steam side of a locomotive slide, it is known as outside lead, or lead for the admission; on the exhaust side it is inside lead, or lead for the exhaust. When the valve is placed at half stroke over the ports, the amount by which it overlaps each steam port, either internally or externally, is known as lap. On the steam side it is named outside lap; on the exhaust side, inside lap. When the terms lap and lead are employed, they are understood to refer to outside lap and lead only.

The advance of the eccentric is a term used to denote the angle which it forms with its position at half stroke, and when the piston is at the commencement of its stroke.

The locomotive slide, as seen in section in the following figure, has neither lap nor lead, but did it extend to the faint dotted lines b b', it would have lap on the exhaust side to both ports; while, on the contrary, if it reached to the dotted lines a a', it would have lap on the steam side. Lap is chiefly used on the steam side. To see what effect this will have, let us examine the top port, and

suppose the slide going up. It is evident if the slide
reaches to the dotted line *a*, as it rises from the bottom of
the upper port, it will close it sooner
against the admission of steam than it
would be otherwise if the slide were
constructed simply as drawn in the
figure; therefore the steam that has
had time to get into the cylinder has
to perform the rest of the stroke ex-
pansively.

LOCOMOTIVE SLIDE.

Lap on the exhaust or eduction side,
b b', is always less than that on the
steam side, and closes the port to the
exhaust sooner than it would other-
wise be, and thus prevents all the
steam from rushing out to the exhaust:
the steam remains behind, and the pis-
ton acts against it as against a cushion,
and all sudden jar and stoppage is
avoided. Sometimes there is no lap, and even *less*
than *none*, or negative lap; then the valve cannot cover
both ports at once. When the slide has neither lap nor
lead, the breadth of the slide face is equal to that of the
steam port, and the travel of the slide twice the breadth
of the port; but when the slide has lap, the travel of the
slide must be double the lap with double the breadth of
the steam port.

82. **Lead.**—Let us suppose that, at the instant the
piston is at the top of its stroke, the slide is in the
position shown in the last figure, but that it extends
only to the top darkly dotted line, then the port at
that instant would be open for the admission of steam :
this is what is called the lead of the slide. Remember
the *lap* is when the *slide* is at its middle position, but
lead when the *piston* is at the end of its stroke. The lap
and lead of the D slide are explained in precisely the
same way, but the steam slide is the inner and the ex-
haust the outer. There is always more lead required in

engines that are driven at great speed, than in those which work slowly. Again, in engines that travel fast, it is best to open the exhaust passage before the end of the stroke, or else the cushioning will act injuriously.

83. To Reverse the Engine with the Single Eccentric. —When an engine is fitted with a single eccentric, the engine is reversed by hand. The engineer notices whether the piston was moving up or down; if *moving up*, he takes the starting bar and admits steam to the *top* of the piston, so that it immediately descends, and the shaft begins to move in an opposite direction. The eccentric is fitted on to the shaft, so that it can be moved halfway round, or rather there are two stops on the eccentric, and one on the shaft. The shaft revolving, as we have just said, moves without the eccentric, so that the stop on the shaft leaves one of those on the eccentric, and when the shaft has moved halfway round, it comes against the second stop on the eccentric, which will be then in its proper position for working the slides, and so the motion of the engine is continued. To throw this eccentric in and out of gear, a recess is cut in the eccentric rod (care being taken that it is in its exact position), to this a pin is fitted to connect it with the slide rod or gab-lever pin. When the engineer has started the engine by hand (by lifting up the slide with the starting bar), and wishes to attach the motion of the eccentric to it, he watches his opportunity and lets the rod fall on the pin; the pin will in half a stroke fall into the recess. It is kept in its place by a bar or strip of iron placed over the entrance of the recess, held there by a spring.

**84. The Double Eccentric, or Stephenson's Link Motion.**—This contrivance, used both in the locomotive and marine engine, was invented by Stephenson to enable the engineer to quickly reverse his engine, and so go backwards or forwards at pleasure.

It consists of two eccentrics, H and G, with their rods A D and C E, the one called the forward, the other the backward eccentric. The two are connected by a link,

D E, with a slotway in it. In the slotway moves the block p, fastened to the end of the valve rod a.

The bell crank lever, D E D, is to move the link up or down. When the forward eccentric is moved, so as to work the valve rod, it moves the slide, and the ship or locomotive goes forward; but when the backward eccentric works the slide rod, the engine is reversed. The link motion is thus a simple and effective mode of reversing the engine expeditiously, and almost without trouble to the engineman.

When we consider that the forward eccentric rod, A D, sends the engine one way, and the backward rod, C E, sends it the other, we see that the travel of the slide has been reversed, as it were. Again, if the pin and link be
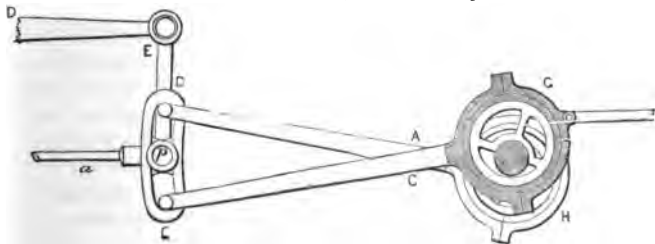
STEPHENSON'S LINK MOTION.

placed in the position shown in the figure, the slide has then but little travel, and we can see that this travel is increased just in the same proportion as the bell crank lever, D E p, moves the link D E up or down from the mid position. As the amount of opening for steam depends upon the motion of the slide, by leaving p in different positions in the slot we open and close the port at and during varying times. This is done by not placing the block at the extremity of the link, but at a distance from it, and resting the lever in its proper place. For this purpose an arc or sector with notches in it is attached to the link motion, to fix the handle in and secure the required opening the engineer may deem best for the

speed required. This is not expansion, but rather wire-drawing the steam. In fact, Stephenson's link motion cannot properly be used to give different grades of expansion, it only alters the travel of the slide; for when the pin is in the middle of the link, the motion of neither eccentric is imparted to the slide rod. The pin being at the end of the link, the slide rod will receive full motion, and full steam will be given to the cylinder; but when the block lies nearer to the centre of the link, less and less steam is given to the engine, and consequently it moves the more slowly. This point is more completely illustrated under the heading "The manner in which the Link Motion distributes the Steam," in the chapter on the Locomotive Engine in the Advanced Work on *Steam* in this Series.

85. Expansion Gear for Marine Engines.—Various plans are adopted by different makers. Some use cams placed on the shaft in such a position that, when the valve is connected with the cam, by an arrangement of rods, levers, etc., steam can be admitted into the cylinder, but when not so, the ports are closed against the admission of steam. The great objection to this arrangement appears to be, that when the roller comes off the cam, it, together with the valve, drops with a sudden jar, which causes a very unpleasant noise in the engine-room, and also a great amount of wear and tear in the machinery itself.

The best plan appears to be to have an eccentric, to which is connected a sliding valve in the steam chest. This eccentric is fixed to the shaft in such a position, that when the valve is in connection with it, it shuts off steam at the required portion of the stroke. The different grades of expansion are regulated by a lever with recesses in it. This is among the connections of the expansion gear. Care is taken, when throwing it out of gear, that the expansion valve is not closed, or else the engine will stop. In some cases the throttle valve is used as an expansion valve, under which circumstance the full benefit of expansion is not gained, for that requires the total cut-off

of steam, which the common throttle valve cannot do on account of its shape, but it wire-draws the steam.

86. A Method of Carrying out Expansion. — The principle of expansion is now carried out in all engines. The end is attained either by *cutting off* the steam from the cylinder by means of lap on the slide valve, or by valves called *expansion valves* preventing its ingress to the slide jacket. The expansion valve is so placed that the steam has no communication with the slide jacket except through the valve.
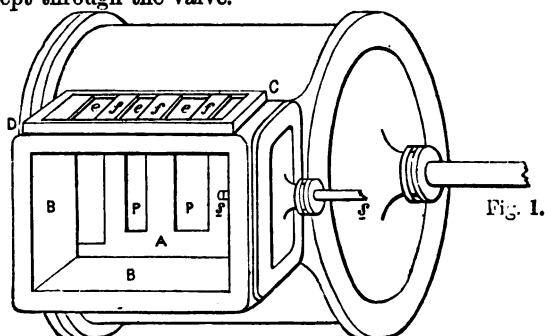

Fig. 1.
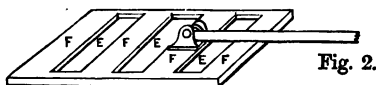
Fig. 2.

EXPANSION VALVE.

The valve now in general use in marine engines, and which is finding most favour with engine-makers, is the gridiron expansion valve; its construction and name being easily understood from figure 2. It consists of a series of ribs F F F, between which are the apertures E E E, through which the steam passes when these apertures are over those of figure 1 marked *e e e*. For the gridiron valve in figure 2 works on the face of D C, the ribs F corresponding to *f*, and opening E to *e*. The steam passes through E *e*, E *e* into the slide jacket B B

below, and thence through the ports P P, etc., into the
cylinder, when the slide valve, of which *s s* is the rod, is
in the proper position to allow it to do so.   If this slide
valve covers the ports P P, of course the steam cannot
pass on; *s s* with its valve receives motion from the ordi-
nary double eccentric, but 2 is moved by the expansion
eccentric figure 3.   The expansion valve is of this parti-
cular construction, the gridiron, to give a large area to
the opening with a short stroke of the valve; for, with
a short stroke equal to the breadth of one of the ribs or
faces F, we have an opening $= E + E + E$, or $e + e + e$.
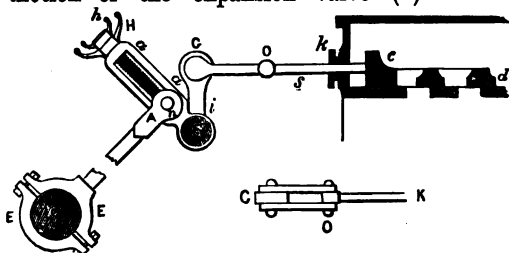The motion of the expansion valve (2) is derived

Fig. 3.   WORKING OF EXPANSION VALVE.

from an eccentric keyed to the main shaft, and is
transmitted to the valve by means of the simple arrange-
ment in figure 3.   We will state again how the steam
passes to the cylinder.   The top or cover of slide casing
is wholly removed in our figure 1, the end of the steam
pipe comes to C D, but the steam cannot pass to B B
until the valve (fig. 2), being moved, will allow the steam
to pass into B B, even then the steam will not enter the
cylinder if the ports are covered by the valve (which is
removed from the ports A A), and of which the spindle is
s s; but when this valve is shifted so as to uncover the
ports, the steam has free ingress to the cylinder.   By this
plan it is evident that valve 2 will give any amount of
expansion by stopping the supply of steam to valve A
(removed).

Fig. 3. Here E E is an eccentric keyed on the shaft S to work the levers of the valve. H is a handle to screw up or down the block through which the pin n passes by means of a square threaded screw, as seen in the figure, working in the block at n, and h is to jam or keep it in its place. When n is moved nearer the handle, the grade of expansion is greater; when screwed down, the opposite is the case. F is the weigh shaft supported by two bearings, not shown in the figure. G i is a short lever answering to the gab lever keyed on the shaft F; to the end G is attached a pair of links to allow for the motion of G not being in a straight line, of which G O is one; to the end O of these links is fastened the valve rod O k. The end of the eccentric rod n moves H F backwards and forwards on the centre F, which moves G i on the same centre, and this gives the reciprocating motion to G O k, and the slide with the requisite amount of expansion. The grade of expansion is marked along the edge at $a\,a$. While the arrangement here described is giving the required amount of expansion, the ordinary link motion is admitting the steam, or cutting it off from the cylinder (fig. 1) by means of the valve removed from A.

87. The Amount of Water Required for Condensation.

—The proper temperature at which to keep the condenser is as near as possible 100° F. or 38° C. At this temperature the steam is sufficiently condensed, while the air pump has relatively the least quantity of water to raise; or, with a maximum amount of useful condensation, we have a minimum amount of water to lift.

Let us suppose the condenser is to be kept at 100° F., and the temperature of the condensing water is 50° F., then out of every unit of water 100° − 50° = 50° of cold are available to condense the steam.

Watt assumed the total heat in steam to be 1112° F. (latent and sensible heat of steam we have called 637°·2 C. or 1147° F.); therefore there are 1112 units of heat to be overcome, which will take $\frac{1112}{50} = 22\cdot24$ units of water; or it will take $22\frac{1}{4}$ more times water than is turned into

steam. As a cubic inch of water produces a cubic foot of steam, it will take 22¼ cubic inches of water to condense one cubic foot of steam.

Watt allowed 28·9 cubic inches, or about a wine pint, for every cubic inch evaporated.

In this calculation we have given the result arrived at by Watt. We will now perform the calculation, using degrees centigrade, making allowance for *the heat which will be left* in the condensed steam, and using the more accurate number, 637°·2 C.

Suppose the temperature of the condenser is to be maintained at 38° C., and the temperature of the condensing water is 10° C., what amount of water will be required for condensation?

The total amount of heat in a given unit of steam is 637·2 units C.

The amount imparted to each unit of water is 38 − 10 = 28 units C.

Of the 637:2 units of heat in each unit of steam, it must give up 637·2 − 38 = 599·2 units.

∴ the units of water required $= \frac{599\cdot2}{28} = 21\cdot4.$

Or, a cubic foot of steam, as it is produced (very nearly) by a cubic inch of water, will require 21·4 cubic inches of water to condense it. More is always allowed, because it is impossible so to arrange the condenser that every drop of water shall at once consume its allotted amount of heat.

The temperature of the condenser will always give an idea as to the vacuum. If the temperature of the condenser is above 100° F., then more water must be supplied for condensation ; if it is below 100° F., then the cocks must be closed a little, as too much water is being used, and the air pumps will have too much work thrown upon them. When the air pumps are labouring too hard, it is one sign that too much condensing water is being used. A thermometer therefore inserted in the condenser will show the state of the vacuum. Generally, the engineman trusts to his vacuum gauge to tell him the state of his condenser. If the vacuum gauge is low, too little water is being used, and he must remedy the defect accordingly.

88. Blow-through Valve.—The blow-through valve of an engine is used to drive out all water from the cylinders, casings, and condensers before starting. It is placed at the bottom of the slide casing so as directly to communicate with the condenser. But sometimes, in the case of the locomotive, one is placed at each end of the cylinder, and worked by a handle from the starting platform. Some engine-makers fit a small locomotive slide and ports for the purpose, which can also be used to start the engines. Before the engine begins work, steam is admitted through the blow-through valve, and the cylinder first cleared of air and water; the steam passing on clears the condenser in the same way, so that, as soon as the engine starts, a good vacuum is obtained in the condenser. This last is the chief object for which blow-through valves are fitted.

S P is the steam pipe; the steam having been brought to the back of the slide cannot enter the cylinder unless the long D slide be lifted up or down, neither can it go to the condenser unless the blow-through valve B be opened by means of the handle *h*. When the valve B is lifted off its seat, then steam can freely pass to the condenser, and blow out all air and water that may be in it; when no blow-through valve is fitted, by the tedious process of alternately letting the steam pass to the top and bottom of the cylinder, and by raising and lowering the slide, the steam may be sent to the condenser, from which it will in time expel the air and water.
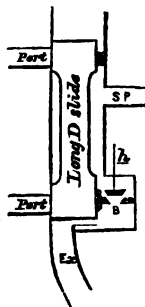
BLOW-THROUGH VALVE.

89. Mercurial Gauges.—Mercurial gauges are and have been used to show the pressure of steam and the vacuum. But as they are very cumbersome, and nearly obsolete, it is useless to describe them, but we may say this much—

(1) **The Long Barometer Gauge.**—The pressure of air corresponds to very nearly 30 inches of mercury, which being about 15 lbs., 2 inches of mercury indicate 1 lb. pressure. A bent tube in the shape of a U, partly filled with mercury, was taken, and one end inserted in the boiler; as the pressure of steam increased, it would drive the mercury down the one part of the tube, in communication with the boiler, and up the other; a graduated scale of 2 inches to the pound showed the pressure of steam in the boiler.

(2) When used as a vacuum gauge, the mercury would follow the vacuum, and rise up the part of the tube connected with the condenser.

(3) **The Short Barometer Gauge** was used to show the vacuum. It was of similar construction to the last; but between the legs, communicating with both, was a reservoir of mercury. As the pressure was taken off the reservoir the mercury fell down one arm, which was short; for as the vacuum between 10 and 15 lbs. only was wanted, the arm was made short, and would remain full of mercury till the pressure fell to 5 lbs. only; so that when the mercury stood 10 inches high, we should have 5 lbs. pressure of air in the condenser; when 8 inches high, 4 lbs., etc.

The mercurial or barometer gauges are old-fashioned, and are hardly used now or fitted to new engines; therefore we have given no figures, merely a short description of them. To these gauges there are scales graduated to every two inches, so that by looking at them the engine-man can tell at a glance the condition of his vacuum. If the mercury stands at 20 inches, then there is $\frac{20}{2} = 10$ lbs. vacuum, or $(15 - 10 =) 5$ lbs. pressure of air in the condenser. If the mercury stands at 24 inches, there is a vacuum of $\frac{24}{2} = 12$ lbs., or the pressure of air in the condenser is $(15 - 12 =) 3$ lbs. Another form of vacuum gauge is this: An iron tube is fixed into the condenser and bent upwards. At the bottom near the condenser is a cock, to open or close the communication with the condenser.

Just above the cock is a small bowl for holding mercury, the tube passing right through the bowl, so that the mercury is round the bottom of the tube and outside it; the top of the tube is open. A glass tube, open at the bottom and closed at the top, a little larger in the internal diameter than in the outside diameter of the iron tube, is taken and placed right over the iron tube, the open end coming down into the mercury. When the communication with the condenser is opened, there being a vacuum within the iron tube, the pressure of the air on the outside pressing on the mercury will cause it to ascend between the two tubes; and, of course, the higher it rises the better the vacuum. It will ascend two inches for every pound. It is graduated, and a scale placed by its side; but as the mercury will sink in the bowl as it rises between the tubes, a pointer or piece of wire is attached to the scale, the end of which, bringing the scale lower with it, must be placed on a level with the mercury before the state of the vacuum is read off. Unless this precaution is taken, the reading is liable to error.

90. **Fly Wheel.**—The fly wheel is an accumulator of power, and assists the crank over the "dead centres." When the crank and connecting rod are in one straight line, as they must be twice in each revolution, the crank is said to be on its dead centre, because there the force of the piston is dead or ineffective. It is evident that when the crank is at right angles to the connecting rod, that the latter has most power on the former, but when the top or bottom dead centre is reached there is no reason why it should not remain there; but the action of the fly wheel then shows itself, for having on it a certain accumulated velocity, it cannot stop, but goes forward, carrying with it the crank over the dead centre. We thus have through the momentum of the fly wheel no perceptible variation in the velocity of the engine, but the unequal leverage of the connecting rod is corrected, producing a steady and uniform motion. The fly wheel, it must be remembered, is a *regulator* and reservoir, and not a creator of

motion, and when no fly wheels are used, as in marine engines, we must recollect that smoothness of motion is not an absolute requisite, and that the momentum of the engines themselves carries the cranks over the dead centres; but far more generally a pair of engines work side by side, whose cranks are at different angles, so that one assists the other at the critical moment. The accumulated velocity of the fly wheel, where the motion is required to be excessively equable, should be six times that of the engine when the crank is horizontal. The efficiency of the fly wheel, in producing uniformity of velocity, is materially modified by the motion of the machinery which the engine is required to drive, and regularity of motion is of much greater importance in some cases than in others; so that in proportioning a fly wheel to a given engine, attention must be paid to many particular circumstances which cannot be given in a general rule.

91. Equilibrium Valves. — Equilibrium valves are those upon which the steam presses with equal force (or very nearly equal force) both upon the top and bottom, being ready to move easily when required. The following figure will give a good idea of an equilibrium valve:—

S is the steam-pipe, through which steam is introduced into the valve-box A B; *a* and *b* are two conical valves on one valve spindle *c d*, kept in its place by the socket *d*. The steam is required to pass at intervals along C. This it will do with full force when the valves are but slightly lifted upwards. It is seen
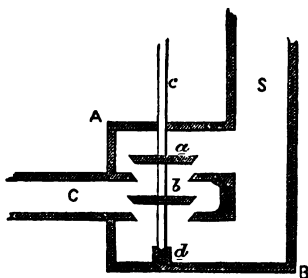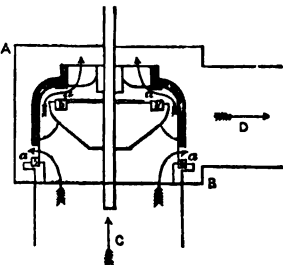

EQUILIBRIUM VALVE.

that if *a* and *b* be very nearly equal, the valve is in

equilibrium, and only a small force is required to lift it, for the pressure of steam on the top of *a* is counteracted by that on the bottom of *b*.

92. Cornish Equilibrium, Double-beat, Crown or **Drop Valve.**—A B is the valve-box. Steam enters it, let us say, from C, and is required to go along D, after passing the valve. It might with equal propriety be supposed to come from D and be passing down C. The part drawn with cross lines or section, is a cylindrical piece of iron fitting down on two rings, *b b* and *b' b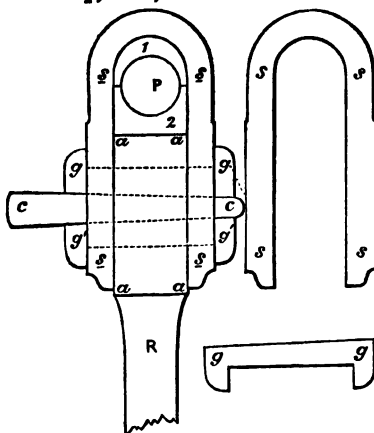'*. The small squares are the sections of the rings; suppose these to go all round. It is evident that when the valve is down on the rings no steam can pass, but as soon as lifted it can rapidly pass through the two openings marked *a* in the paths indicated by the arrows. These openings extend all round in a circle. A very slight movement gives a large opening for steam. The seats *b b* and *b' b'* are called the beats. Sometimes these valves are made with three or four beats.

CORNISH DOUBLE BEAT VALVE.

93. Escape Valve.—The escape valve should have been noticed when describing the cylinder. They are fitted in the top and bottom of the cylinder, being kept in their places by weights or springs. Water that gets into the cylinder through condensation or priming, as it is incompressible, would inevitably break something, were not provision made to allow it to escape through the escape valves. They are loaded with a weight or spring greater than the pressure of steam in the boiler. *Test* or *pet cocks* are also fitted to the tops and bottoms of the cylinders in marine engines for the same purpose. They are opened on starting the engine, and shut

when properly under way. The escape valves are *always* ready to act, and are held in their places by weights, which keep them closed only so long as the pressure in the condenser is below that in the boiler.

Strap, Gib, and Cutter.—The ends of the connecting rod are not, as it were, part of the rod, but are built up upon the end of the rod itself.

Let us take the annexed illustration, which is the smaller end of a connecting rod; *a a a a* is the end of the rod with a hole in it; first upon the end are placed the two brasses 1 and 2, in which a circular hole is left for the crosshead pin to pass through; round the hole is placed the strap *s s*; then into the hole is placed the *gib g g* (in this case we have two gibs, *g g* and *g′ g′*); then the *cutter* or *key c c* is driven in tightly, so that the whole is held firmly together. Sometimes *c* is also held in its place by a screw and nut.

STRAP, GIB, AND CUTTER.
SMALLER END OF CONNECTING ROD.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. In what way is steam admitted into the cylinder. How is the apparatus worked (1865)?

2. How is steam admitted into the cylinder? Describe with a sketch the usual mode in marine engines for working the gear connected with the slide (1868).

3. Describe with a sketch some form of slide valve as connected with the steam cylinder of engine, and explain its action (1869).

4. Draw in section the cylinder and slide valve of a double acting engine, and explain the manner in which the valve regulates the admission and exit of the steam.

5. Describe with a sketch the single acting engine (1871).

6. Describe the long D slide (1867).

7. What is the use of the expansion valve? Show by a diagram the pressure of the steam in different parts of the stroke when worked expansively (1867).

8. Describe the barometer gauge in common use (1867).

9. What is meant by the terms cushioning and clearance?

10. Does the amount of clearance above the piston of a side lever engine usually increase or diminish as the engine wears (1868). See next chapter.

11. Describe the Cornish double-beat valve (1868).

12. Describe the method of working a slide valve by an eccentric (1869).

13. There are three valves connected directly with the steam cylinder in Watt's single acting condensing engine, name them. During what portions of the up and down strokes of the piston should these valves be respectively open or shut? and for what reason (1871)?

14. Valves used to close a passage through which steam or water under pressure may be required to pass are so constructed as to be capable of being lifted against this pressure with a very small expenditure of force—sketch a valve of this kind, and explain its action (1871).

15. Describe some form of slide valve as fitted to the steam cylinder of a double acting engine. Sketch the valve in section with the opening over which it slides, and give it some amount of lap on the steam side. How is the face of such a valve made truly plane (1871)?

16. For what purpose are escape valves fitted to the cylinders of marine engines? How are such valves kept closed, and what determines the least amount of load which must be put upon them (1871)?

CHAPTER VI.

THE MARINE STEAM ENGINE AND DETAILS.

Side Lever Engine—The Oscillating Engine for Paddle Steamers —The Vertical Trunk Engine—The Gorgon Engines—The Object of this Arrangement—Other Forms of Engines— Engines for Screw Propellors—Direct Acting Engine with or without Multiplying Gear—Penn's Trunk Engine—Maudslay and Field's Return Connecting Rod Engine—Details of Parts connected with the Working of a Marine Engine—The Air Pump Bucket and Valves—Double Acting Air Pump— India - Rubber Disc Valves — Cylinder Escape Valves — Bilge and Feed Pumps—Expansion Valves—Expansion Cams and Gear.

ENGINES are first divided into two classes :—

    (1) CONDENSING ENGINES, miscalled low-pressure.
   (2) NON-CONDENSING ENGINES, miscalled high-pressure.

We should avoid the use of the two terms high and low pressure, as they are scarcely applicable to engines of the present day.

94. **Marine Engines** are generally divided into two classes—those adapted to drive the paddle wheel, and those best suited for the screw. The chief difference seems to be, that engines to drive the screw are *direct acting*, *i.e.*, their piston-rods are directly attached to a crank on the shaft; while in the case of paddle wheels they are not always *direct acting*, but the motion is conveyed through the intervention of side levers. In the direct acting engine, it is often a prime object with the

engineer to obtain a long stroke. To gain this end, many
of the various modifications in marine engines have been
suggested.

But let it be well understood that no particular engine,
perhaps with the exception of the side lever, is entirely
confined to either class. Every student should seek
opportunities to examine the engines in his neighbour-
hood as minutely as possible. An hour spent in this
way will sometimes add more information to the student's
repertory than days at his books alone.

95. The Side Lever Engines.—The first engine em-
ployed to drive the paddle wheel was a side lever, in
which the ordinary beam pumping engine was modified
to obtain the requisite rotatory motion, and the beam
placed by the side of the cylinder, condenser, etc., to
stow it into as compact a space as possible. In the ori-
ginal side lever, the end A of the beam A B is worked up
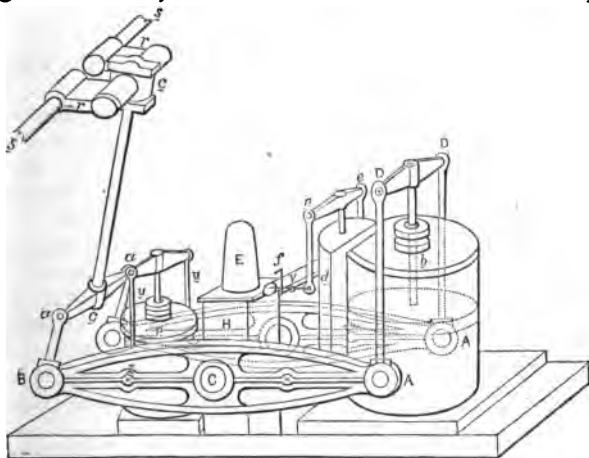
SIDE LEVER ENGINE.

and down on its centre C by the side rods A D, while to
the end B is attached the fork head *a a* of the connecting

rod *c c*, which works the crank *r r*, giving the circular motion to the paddle shaft *s s*.

A A shows the cylinder with the piston within indicated by dotted lines. The piston-rod comes through the *stuffing box b*, and is attached to the cylinder crosshead D D, working the levers A B as previously stated.

The slide casing is seen at *d*, and the slide crosshead is *e e*. The eccentric is attached to the gab lever *f*, which gives the necessary motion to the slide side rods and slide.

E is the air cone standing upon the top of the hot well H.

P is the air pump with its side rods *u u* joined by the air pump crosshead. The piston of the air pump works through the usual stuffing box, as seen in the figure, taking the water from the condenser, which lies immediately beneath the engine, extending from the bottom of the slide casing to the bottom of the air pump. The water is driven into the hot well H, and out into the sea.

In connection with the slide side rods, are the weigh shaft, the back balance *v*, and the valve lifter.

96. Oscillating Engines are a triumph of engineering skill. They have been brought to their present perfection chiefly through the ingenuity and skill of Penn. Murdock, in 1785, attempted an oscillating engine; but the accuracy of our present fitting shops, and the skilful contrivances of modern machinists, were not at his command, so there is no wonder he could not perfect his ideas.

In oscillating engines, instead of the connecting rod oscillating to the motion of the crank, the cylinders oscillate and the connecting rod is dispensed with. It possesses many advantages; among others, it occupies but little space, consists of but few parts, and is easily accessible for repairs.

The two cylinders A B and C D vibrate each upon two trunnions, only one of which, *a*, is shown in the figure. These trunnions are placed about the middle of the outside. The steam enters through the outside trunnions, or

those nearest the sides of the vessel, whilst the exhaust steam escapes at the opposite sides, or into the condenser placed below and between the two cylinders. The air pump is within the condenser, and is worked by a crank on the "intermediate shaft." The shaft that stretches over the engines from cylinder to cylinder is called the
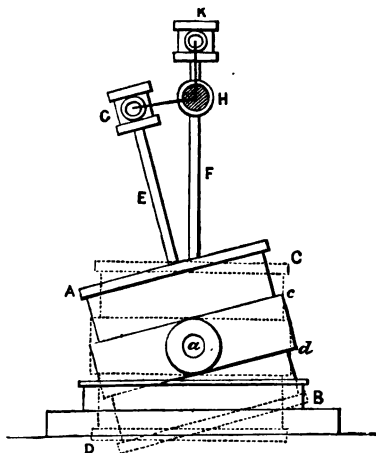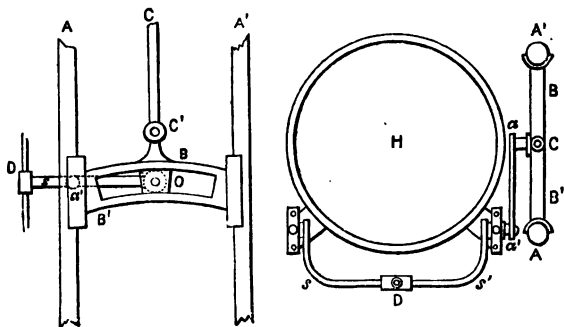

OSCILLATING ENGINES.

intermediate shaft, the slide valves are worked by eccentrics on this shaft, but the particular mode of working is explained in the next paragraph. We must not omit to mention, that the steam first passes into a belt *c d* on the cylinders, and then, after going partly round, enters the ports at the proper time. E and F are the piston-rods, G H and K H the cranks turning the main shaft H.

97. How the Slides in Oscillating Engines are Worked.—In oscillating engines of small power, the oscillations of the cylinder are made to work the slide valve.

It will not do to connect the eccentric rod in oscillating engines on to the slide valve rod, on account of the motion of the cylinder. The difficulty here encountered is overcome by having a sector B B′ sliding in between two upright rods A A′. The eccentric rod C C′ is attached to the sector by means of a pin C′, so that motion is given to the sector by the eccentric. Within the sector slides


WORKING OF THE SLIDES IN OSCILLATING ENGINES, AND DETAILS
OF SLIDE GEAR.
(The letters in each figure correspond).

a block O, to which is fastened the gab lever a a′ (right hand figure), the spindle of which rests on a bearing a′ attached to the side of the cylinder H; to this also is attached the valve lifter s s′, which gives motion to D, the slide valve rod, so that the movement of the eccentric is thus transferred to the slide valve. The slotway in the sector is an arc, the centre of which is the centre of oscillation of the cylinder. The motion of the cylinder cannot, therefore, have any effect on the slide valves if the block of the gab lever pin move freely in the sector, which it does. In this manner, therefore, the eccentric works the slide valves as in ordinary cases.

98. Steeple Engine.—Steeple engines have been introduced largely on the Clyde, they also find much favour in America. They are direct acting engines, very

serviceable and compact, and found to answer very well as river steamers.
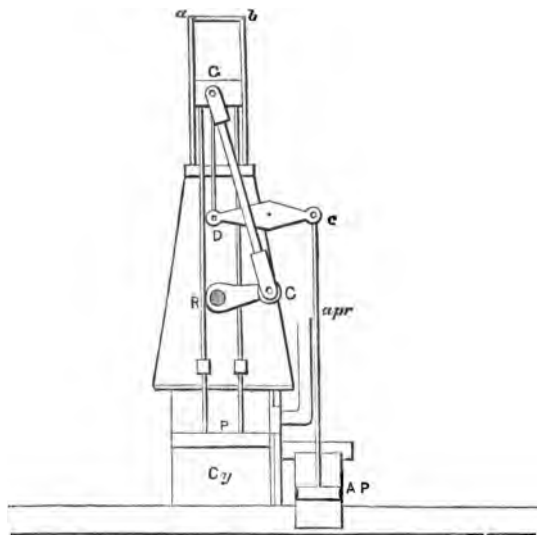

STEEPLE ENGINE.

They have not, in consequence of the high erection they require above the deck, found any favour as sea-going vessels, but the objection against them from this cause seems more theoretical than practical. They do certainly present a surface to the action of the wind, but this action may very often be in favour of propulsion, while the surface is but small. They acquire their name from the high erection $a\,b$, which serves as a guide for the end of the connecting rod, which is above the crank.

Cy is the cylinder; P the two piston-rods, as shown in the figure, move the guide block G up and down between the guides $a\,b$. G C is the connecting rod converting the reciprocating rectilinear motion of G into a continuous circular motion by means of the crank C R, which is thus

conveyed to the shaft marked dark in the figure. A P is
the air pump, *a p r* air pump rod, worked by means of
the air pump lever *c* D, which receives its motion from
the guide block.

**99. Maudslay's Twin Engine, or Siamese Engine, or
Double Cylinder Engine.**—There are two cylinders, A and
B, and two piston rods, *a* and *b*. These rise and fall
simultaneously, carrying with them the large crosshead
C D in the form of the letter T. The part E F descends
between the two cylinders, the sides of which serve as a
guide, so that the guide block F is compelled to move
perpendicularly, and so preserve the parallelism of the
piston-rod. To F is attached the connecting rod F G,
which moves round the crank G H, carrying the main
shaft H.
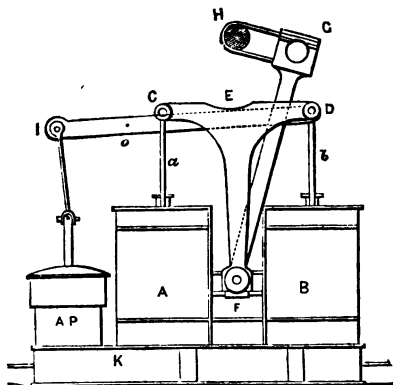
DOUBLE CYLINDER ENGINE.

The air pump A P is worked by the lever D I, reci-
procated by the end D of the crosshead, and moving on
its centre *o*. The condenser is low down at K—this
has proved an objection under certain circumstances.
This engine is only fitted for driving a paddle wheel.

100. Beam and Geared Engine.—Some engineers do

not admire driving their engines at a high speed of the piston, although it is necessary to have a high speed at the screw. A beam engine is often put into the ship which works a large spur wheel, from which is driven a smaller pinion. A moderate speed of the crank shaft may be kept up, which will give a very fast speed to the screw, on account of the smaller size of the screw shaft pinion compared with the driving wheel.
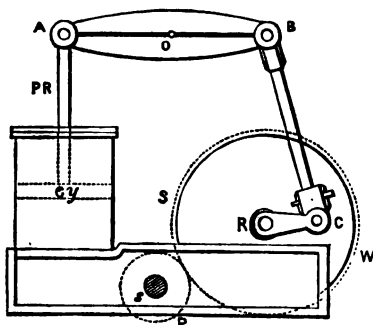

GEARED ENGINE WITH BEAM.

C*y* is the cylinder, the piston rod (P R) of which gives the necessary reciprocating motion to A B, moving on its centre O. B C is the connecting rod, R C the crank turning the spur wheel S W, which works the pinion P, keyed on to the main shaft *s*. It will thus be seen that one revolution of the spur wheel S W (or one stroke of the engine) will give several revolutions to the pinion P, or to the main shaft.

101. Trunk Engine.—Watt first gave the idea of a trunk engine, but it was not fully developed till Penn produced the direct-acting horizontal marine screw engine. Each engine is generally worked by two cylinders. The cylinder A B is laid on its side; and down the centre, passing through both ends of the cylinder, goes a large trunk *a b*, on which (all in one piece) is cast the piston

S I   G

c d, so that the effective working part of the piston is an annulus or ring. The trunk is fitted steam tight by means of stuffing boxes. The connecting rod is attached to a pin *o*, fixed in the middle of a trunk, while the other end engages and works the crank *c s*, where *s* is the main shaft.
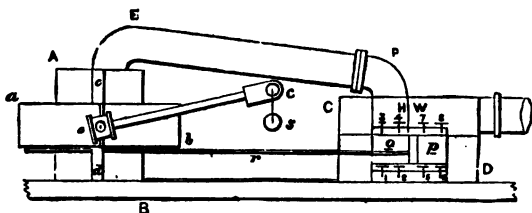

TRUNK ENGINE.

C D, the rectangular figure to the right, is the condenser, divided into the condenser proper, the hot well, and the pump barrel. The large pipe E P is called the eduction pipe; its purpose is to bring the exhaust steam into the condenser, where it is condensed at the bottom, after which the double acting pump *p* delivers the water into the hot well H W.

102. Gorgon Engines.—*Gorgon Engines* constitute a class by themselves. They are adapted for driving paddle wheels. We will endeavour to explain the principle of their construction. As a class, they have been strongly condemned by some eminent engineers, while others approve highly of them. Their length is less than that of a side lever, while the connecting rod is short— a great evil. The shaft is often very high, which acts disadvantageously. They have an ordinary cylinder, piston, piston-rod, connecting rod, and crank; the steam is admitted in the manner indicated in the article on Seaward's slides. From the exhaust side of the cylinder the steam is led to the condenser, the arrangements for which with the air pump, foot valve, delivery valve, and snifting valve, are much the same as explained under the heading Watt's Improvements. Its distinctive features

áre the manner in which the steam is admitted to the cylinder, and the parallel motion. On the top of the hot well is fitted a vertical frame, named the "rocking standard," the lower end so connected as to allow the top to move or rock backwards and forwards through a very small arc; to the top of the rocking standard is attached the "rocking beam," one end fastened to the end of the piston-rod, the other to the intermediate rod at the end of the pump rod. To this rocking beam is attached the bridle rod, the other end being secured to the frame of the engine— the whole forms the parallel motion. The air pump rod is kept vertical by guides, but the piston-rod by the bridle rod, rocking beam, and rocking standard. The object of the arrangement was to secure compactness, so that the engine might take up as little room as possible.
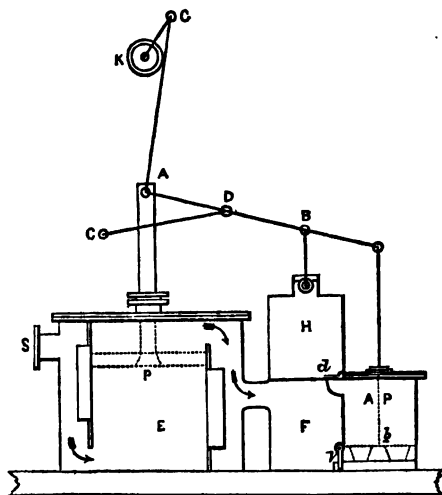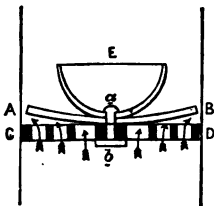

GORGON ENGINE.

E is the cylinder, P the piston with its piston rod attached. Steam enters the cylinder by way of S, in

the direction of the arrows, and drives the piston up.
The steam that drove it down goes out, as shown by the
two arrows on the right hand, to the condenser at F,
where it is condensed, the water passing the foot valve v,
after going through the air pump bucket b, is delivered by
the air pump A P through the delivery valve d into the hot
well H.   The piston-rod is joined to the connecting rod
A G, which works the crank G K, turning the paddle
shaft K.   The *parallel motion* is C D A B.   C D is the
bridle rod, A B the rocking beam, and B H the rocking
standard.   The point B describing a very small arc,
which may be considered a straight line; the end a compels
the piston rod A P to move perpendicularly and thus pre-
serve its parallelism.   C D = A D = D B.   S is the
steam side of the cylinder, and the right hand is the ex-
haust side.

103. **Air Pump, Bucket, and Valves.**—Many kinds of
valves are used for the air pump.   Metallic valves are
frequently objectionable in consequence of oxidation, but
chiefly because of galvanic action.   They are generally
packed with hemp, metallic rings being unsuitable.   In
the engines first constructed, the ordinary "butterfly
valves" were used; but as engines in course of time
were made more powerful, a greater weight was thrown
upon the air pump, and other forms of valves were
adopted.   One of the best for the purpose is the

India-rubber Disc Valves.—These are employed,
especially in swift running
engines, for air pump valves,
instead of the common butterfly
or clack valves.   They are con-
structed with a ring or disc of
India-rubber covering a grating.
A B is a circular piece of good
thick vulcanized India-rubber;
C D is the grating over which
it is fixed; the arrows show
the direction in which the water passes.   The grating is

INDIA-RUBBER DISC VALVE.

very similiar in construction to those employed for air-gratings in floors. E is the guard full of holes to keep the India-rubber from collapsing into a heap. All these are bolted together by the bolt *a b*. When water has passed through the apertures in CD, and the pump ascends, the pressure of water on and above A B lays it flat on C D, so that none can return. But on the down stroke, the India-rubber being pliable it gives way, and the water passes above the valve.

104. Double Acting Pump.—A double acting pump is one that delivers water both by the forward and back-ward stroke. Penn's trunk engine is always fitted with two of these air pumps, one to each cylinder; each is worked by a rod which passes through the piston and cylinder cover, and there are, of necessity, two suction (foot) valves, and two forcing (delivery) valves. The feed and bilge pumps are worked in the same manner.

Let us suppose the air pump piston is at the end of its stroke to the right, then the space in front of it, or near the cylinders, will fill with water from the foot of valves 1 2; when the piston moves to the left it will carry with it the air pump piston by means of the rod *r* to the left, so that the water filling *o* will be forced through the delivery valves 3 and 4. As the piston moves to the left a vacuum is left behind it in *p*, so that water rushes through the suction valves 5, 6, while forcing valves 7, 8 close by pressure from above. In a similiar manner, but by opposite action, the stroke delivers water into the hot well H W, as the piston moves from left to right.

Another kind of double acting pump is a simple arrangement, by which the same pump can be made to force water either in or out of the ship, or in or out of the boiler. The pump is worked by the usual arrangement of valves; but there are two tapheads placed in the valve box which turn two circular spaces. When turned in one direction, the suction acts to bring water into the ship; but when turned in an opposite way, water is forced

out by simply changing the direction from whence the water can get beneath the valves.

105. Bilge Pumps.—A *bilge pump* is fitted to relieve the ship of the water that, by leakage or otherwise, may gain access to the bottom or bilge of the vessel. A bilge pump is generally fitted with a plunger, as shown in the feed pump in the article on page 68. It has a foot valve, through which the water comes when the vacuum is made, and a delivery valve, through which it is driven when the plunger descends into the water. The plunger is generally worked by the air pump crosshead, and the water driven overboard through a pipe fitted on purpose. Sometimes arrangements are made so that the bilge water can be used for condensing purposes; this of course can only be employed, and then it would be of great service, when the ship springs a leak. There is always a risk in using bilge water, lest chips, oakum, etc., should get in and injure the valves, or prevent them properly working; but if the entrance to the pipe be well protected and looked after now and then, this risk may be reduced to a minimum.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. Describe some form of engine for driving a screw propeller. Define the terms pitch and length as applied to a screw propeller (1870).

2. Describe the general arrangement of a pair of oscillating engines for a paddle wheel steamer. Since the slide valve oscillates with the cylinder, how should it be connected with the eccentric upon the fixed shaft which drives it (1871)?

3. Describe the general arrangement of the trunk engine for driving a screw propeller. Describe also that of an oscillating engine suitable for a paddle wheel steamer (1869).

4. Describe generally the side lever marine engine. What is the object of the blow valve, and where is it placed? Which parts of the engine are made of brass, and which of cast or malleable iron (1870)?

CHAPTER VII.

THE PADDLE AND SCREW.

Paddle Wheels—Feathering of the Floats—Disconnection and
Immersion of the Wheels—The Screw Propeller—Various
Forms—Length, Angle, Pitch, and Area of Screw Blade
—Disconnecting and Raising the Screw—The Position of the
Screw Propeller in the Vessel—The Slip of the Screw—The
Method of Receiving the Thrust upon the Vessel—Soft Metal
Bearings.

THERE are various methods of propulsion, but up to the
present time only two have done good work—

               (1) PADDLE WHEELS.
               (2) THE SCREW.

In addition to these two, the "Waterwitch" is driven
by a kind of turbine or hydraulic propulsion, which shall
be explained.

Vessels in every case are propelled through the water
by leverage. The only fulcrum obtainable is the water
itself, which cannot offer any resistance to the slightest
pressure applied to it without yielding to a certain extent.
The amount of yielding will vary with the pressure and
the quantity of water acted upon. Without this yielding
property of the water, no vessel could progress through it
at all. The problem to be solved in marine propulsion,
is to arrange the floats, screw, etc., that with the least
amount of slip we may attain the highest speed of pro-
gression.

106. Paddle Wheels consist of two large wheels moving
on the end of the engine shaft. They are made with iron

arms attached to two large rings, on to which are bolted
the paddles or floats. As they are turned round, the
resistance offered to them by the water causes the vessel
to move, acting precisely on the same principle as a boat
oar; by them the inertia of the water is made a means of
locomotion. In using this appliance as a motive power,
its advantage mainly depends upon the amount of im-
mersion. When the water approaches the centre, or
reaches above, it is obvious that the greatest waste of
power will ensue. It is quite as obvious that the greater
the diameter of the wheel the greater the leverage, and
the greater is the effect obtained. The floats are generally
made of elm or pine. There are various kinds of paddle
wheels, such as (1) The ordinary radial wheel; (2) the
cycloidal; (3) Morgan's feathering paddle.

107. (1) The **Ordinary Radial Wheel** has the floats
fixed on the radial arms. It is to be observed that in this
arrangement the floats enter the water with the whole of
their faces presented to it; the same action takes place as
they come out. From this arises a great loss of power,
for they should evidently offer the greatest resistance to
the water when at their lowest point, and none when
entering or leaving. From this cause, and the yielding of
the water, the ship does not move so fast as the wheel.
The loss is called slip, and is generally allowed to be 20
per cent.

Slip is the difference between the speed of the wheel
and the speed of the ship. The percentage is calculated
on the speed of the wheel.

108. (2) **Cycloidal Wheels.**—To obviate the difficulties
and disadvantages of the ordinary wheel, other forms have
been suggested, as the Cycloidal, which merely consists
in dividing the float into two strips longitudinally. The
one farthest from the centre is behind the radius, and the
other in front of it. The intention of this arrangement is,
that the floats may meet the water with more uniformity.
It is a very good form of wheel for large vessels.

In order that the floats may enter and leave the water

with the least possible resistance, they should enter in a
tangential direction to the curve which is being described
by any point in the wheel. This is, as is well known,
the cycloidal curve.

109. (3) **Morgan's Feathering Paddle.**—A wheel of
this kind was first patented by Galloway in 1829.

MORGAN'S FEATHERING PADDLE.

The figure at a glance gives us a good idea of the prin-
ciple of the feathering paddle. The floats are seen sup-
ported on spurs attached to the rim of the wheel. The
long levers $a\,a\,a$, etc., move the short ones $a'\,a'\,a'$, etc., on
their centres $b\,b\,b$, etc., fixed on the spurs. The levers
$a\,a\,a$, etc., proceed to a centre C, while o is the *centre* of
the *wheel*. Thus the centre of the floats is not coincident
with that of the wheel. The centre C is either driven by
an eccentric on the ship's side, or "by a rigid bar which
springs from a solid ring" * By this plan the floats are
always moved on their centres, so as to enter and leave the
water very nearly perpendicularly, and also offer the
greatest resistance at the lowest point. The floats are, in
fact, constantly at right angles to the surface of the water

* Goodeve's *Mechanism*, p. 251.

when immersed. Feathering the paddles simply means arranging them so that they shall enter and leave the water in a vertical position.

110. Immersion of Paddles.—The great difficulty with paddle wheels is to secure a proper immersion. As the ship proceeds on its voyage and consumes its store of coals, the vessel becomes lighter, and, consequently, its draught of water decreases. Therefore, supposing a paddle is properly immersed at the commencement of a voyage, it will be nearly out of the water at the end. At the commencement of a voyage the paddles *must be* too deeply immersed, at the middle the proper immersion will perhaps be attained, while there will be too little towards the end of the voyage. It is usual to allow from twelve to twenty-two inches of water over the top of the floats, according to the size of the ship; but in river steamers the usual plan is to allow only about one inch over the floats, or that they should be just awash. A system of reefing the paddles exists, *i.e.*, at the commencement of the voyage the floats are reefed, or unbolted, and fixed nearer the centre, and as the coal is consumed they are shifted outwards to the end of the radii.

111. Disconnecting the Paddle.—When the wind is fair for sailing, and the ship is placed under canvas, it is usual to disconnect the paddle wheels from the engines, and allow them to revolve in their bearings by the resistance of the water. Several plans have been proposed to permit this action, as Maudslay's plan of sliding the paddle shaft with the nearest crank out of the crank pin by means of a worm wheel.

Braithwaite's, which consists of a cast iron disc keyed on to the paddle shaft; surrounding the cast-iron disc is a strong wrought-iron hoop, which will slide round the disc. A projection, into which is bored an eye for the crank pin to pass through, is forged on to the hoop; on the opposite side of the hoop it is enlarged to cover a brass cushion; this cushion is driven by a key tightly against the cast-iron disc, when the friction is so increased

as to cause the disc to carry round the hoop, and with it the crank, and so motion is communicated to the wheels. Of course, if the key be driven out, then the hoop and disc revolve independently, and the wheel is free to move by the resistance of the water.

112. **The Centre of Pressure.**—In Morgan's feathering paddle, as each paddle is always perpendicular to the water, they progress with the same horizontal velocity, therefore we may safely say, that the point of maximum resistance, or centre of pressure, is in a line passing longitudinally along the centre of the float. But in the radial wheel this cannot be the case, for the outside edge of the float moves much faster than the inside; the point where these two average each other is taken at a distance of *one-third* the depth of the board from the outer edge.

113. **The Rolling Circle** is that circle described by the point in the wheel whose velocity is equal to the velocity of the ship. It is evident that the centre of pressure moves faster than the rolling circle; the resistance which this difference of velocity gives, is that which propels the ship.

"To the full power of the steam engine, and a certain draught of the vessel, corresponds a certain rolling circle, which indicates the maximum performance of the vessel. Under no circumstances whatever can this maximum efficiency be obtained if the centre of the float of a paddle wheel is placed on the rolling circle. Wherever beyond the rolling circle the floats of a paddle wheel may be placed, and however great the slip of the float, so long as the rolling circle is kept at this maximum, slip, under such circumstances (as, for instance, in a small float placed at a distance from the rolling circle), is no loss of power, and does not lessen the efficiency of the engine." *

Paddle-wheel steamers are best adapted for propulsion on shallow rivers and lakes, where the draught of water is limited.

114. **The Screw.**—It need scarcely be said that the paddle wheel was the first mode of propulsion used, and

* *Engineering.*

that paddles possess certain advantages, under peculiar circumstances, by which they still retain a strong hold upon marine engineers.

115. The Screw or Propeller, or Screw-Propeller.— The form is that of the screw of Archimedes, or it is a spiral similiar to the geometrical staircase. It acts at right angles to the paddle wheel, and is fixed in the dead wood at the stern of the vessel, a large rectangular hollow being constructed on purpose for its reception.

The propeller is of the same construction as the common screw, but the narrow thread of the latter is expanded into the large thin plate in the former, while the central cylinder of the screw becomes very small, and only a very small part of a convolution is taken, as it has been found that one-sixth part of a convolution is much more effective, and will do more work, than the whole. Propellers are generally made with two blades, but they have been used with three, four, and six blades. The former are found to answer best, being fixed on a spindle passing through a boss.

116. Pitch, Thread, Angle, Length, Blade, Diameter, Slip.— We may suppose a screw to be formed thus:— Take a piece of paper in the form of a right-angled triangle, as A B C, and wrap it round a cylinder, such as a large lead pencil or ruler. Let us suppose that when it is wrapped round, the point C touches B, or the side B C exactly fits round once. Then A B is the *pitch*, B C is the *circumference*, A C the thread, and A C B the angle. The thread on our supposed screw is only a line; let us suppose this, as was said above, to become a wide flat plate wound round, and that the cylinder becomes small, and that of the whole thread only two bits are taken opposite each other, we shall then have as good an idea of a screw as can be given.

The **Pitch** is the distance that a complete convolu-

tion takes upon the cylinder; or the pitch, as in the common screw, is the distance between two threads; or, thirdly, the pitch is the distance that the screw would go if turned once completely round in some unyielding substance.
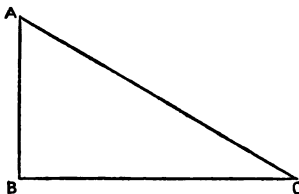
The Thread is the distance along the edge of the blade.

The Angle is the inclination of the thread of the screw.

The Length is the fraction of the pitch actually used.

Blade.—Each propeller consists of two or more parts, which are called blades. The *area* is the surface of the blade.

Diameter is the diameter of the cylinder from which the screw is taken, or it is the perpendicular distance between the extreme outside points of the blade.

Positive Slip is the difference between the speed of the ship and the speed of the screw. Slip varies from 10 to 30 per cent.

Negative Slip.—It is a curious fact that vessels have been propelled *faster by the screw*, than the screw would have gone had it been working in an unyielding substance. The difference between the velocity of the ship and the screw under this circumstance is called *negative slip*. It has been suggested that the lines of the ship were such, that a large body of water followed the vessel and re-acted upon it, assisting the screw to send the ship forward. If we consider the condition of the water around the screw and behind it, we shall see a better reason for this singular fact. The water is thrown outwards and backwards by the propeller in the form of a *hollow cone*. Obeying the usual laws of nature, the water follows to fill up this hollow, and it thus comes again to the screw in two directions. First, that which follows in the wake of the vessel; and second, that which attempts, as it were, to fill up the vacuum near the centre, caused by the centrifugal action of the propeller. Both these bodies of water will impinge upon the screw, and cause an additional thrust. From this we can conceive that negative slip

may exist when these two forces reach a maximum, and
act under peculiar circumstances.

There are many varieties of screws, such as Griffiths',
who bends the ends of his blades forward a little, and
makes them broad at the boss.   He discovered, in com-
mencing a series of experiments, that when he placed a
hollow globe, one-third the diameter of the screw, as the
boss, that thereby a positive gain was effected.   The
blades of his propeller do not spring from the shaft,
but from this hollow sphere.   The reason for such an
apparently anomalous arrangement will be found in what
follows.   To move the central portion of the screw and
blades, absorbs through their inertia and resistance nearly
twenty per cent. of the power of the engines, while these
parts do little towards the propulsion of the vessel.   For
they are nearly in a line with the shaft, or at right angles
to the water, and so cannot effect such a displacement
of water as shall react on the ship.   Griffiths constructs
his blades to incline forward, the curve beginning from
the centre of the length of the blade, and reaching to its
point towards the ship.

Different engineers have given their blades the most
varied shapes.   The object has been to get rid of the
vibration which communicates itself to the hull of the
ship, and is the cause of that disagreeable tremulous
motion experienced in screw vessels.   This vibration
must result from the screw striking the water at intervals,
and not acting as it should with a continuous pressure.
The unequal pressure is frequently caused by the blade
being too wide across the top.   Were the speed of the
ship the same as that of the screw, this "shivering" would
not occur.   Engineers round off and spoil their screws to
make them cut the water instead of striking it, when they
should make the pitch finer in relation to the diameter,
and the blades narrower, but retaining their natural form.
The greatest resistance of the water is "across the pro-
pelling side of the front surface just across the middle, and
the forward side of the leading edge of the back surface."

117. Feathering Screws.—Several methods have been proposed to feather the screw, such as Maudslay's and Bevis' methods.   To feather the propeller is to resort to such an arrangement that the two blades can be turned into a line with the keel of the ship, or in a fore and aft direction, when she is under canvas.   Bevis' method feathers the screw by means of two levers working in a boss on the screw shaft; the levers are moved by a sliding rod passing through the *hollow* stern shaft.   The sliding rod is worked by a nut on the shaft, while the whole apparatus is easily accessible in the shaft tunnel.

118. Twin Screws.—Twin screws consist simply of two screws, one on each side of the rudder, instead of one screw in the dead wood in front of the rudder.   One screw turns to the right hand, the other to the left.   It is claimed for this arrangement that the ship can be very quickly turned within a small space.

119. Disconnecting and Raising the Screw.—We have stated that Maudslay makes provision for feathering his propeller, or for arranging it so that when the ship is under sail, it shall offer no resistance to the water.   It has been found before now, that when a ship has been under sail and steam at the same time, that the velocity of the ship has outstripped the velocity of the screw; hence the screw has dragged or become an obstacle to the progression of the vessel.   Cases have been known in which the screw has actually been broken off backwards or away from the ship by this dragging force.   The screw also requires to be sometimes taken out for examination and repair, therefore a necessity exists for providing means both for disconnecting the screw from the engines, and for raising it out of its place.   Merchant vessels are generally brought alongside a quay at high water, and at low water the screw is examined or taken out—the process often involving considerable expense from loss of time, etc. But in men-of-war more complete arrangements exist. The screw is fixed in the centre of a frame, supported on a short shaft.   The main screw shaft can be withdrawn,

and thus the screw is *disconnected* from the shaft, and is
at liberty to revolve; by an arrangement of slots, it and
its frame are also perfectly free to be lifted out vertically.
This is effected by means of ropes and other appropriate
tackle, or by a rack and worm.

Admiral Hall has proposed a simpler and less expensive
plan for shipping or unshipping the propeller in any
harbour without entering a dry dock.*
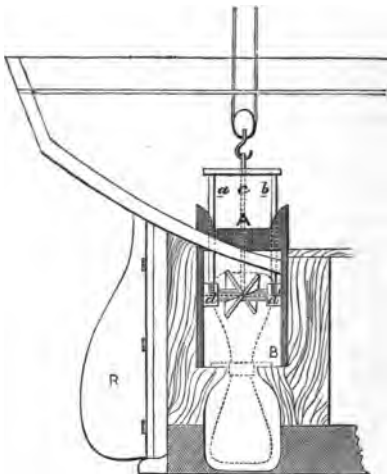
ARRANGEMENT FOR LIFTING THE SCREW.

The screw is fixed in a frame A B, and the screw shaft
can be withdrawn.   A is the crosshead of the frame
through which pass two rods, *a* and *b*, which are screwed
into the tops of the bearings at *d d'*; *c* is a strong chain
to hold the screw.   First of all, the propeller is raised as
high as possible from the place shown by the dotted lines
to the position as seen in the figure by means of the
screws.   Then tackling is fixed to each end of the blade,
and *c* is also fastened on.   Next the rods *a* and *b* are

* A full description will be found in *Engineering*, Vol. VIII., p. 43.

unscrewed and taken out, when c sustains the propeller. The tackling fixed to the ends of the blades is supported by guys, so as to run clear of the sides of the vessel. Next c is let go, and as the right chain-tackle is slackened, the left is wound up, bringing the propeller out sideways and carrying it on to the deck. To ship the screw, these proceedings are reversed.

The same figure will also give us an idea where and how the screw is fixed in the dead wood, and its position as regards the rudder R.

120. Thrust of the Screw.—When we consider that the screw acts by the resistance offered to the surface of the blades by the inertia of the water, which is driven sternwards by the screw, we perceive at once that the whole force moving the vessel is transmitted to the end of the screw-shaft. Methods must therefore be provided to prevent the force or motion from being converted into heat by the enormous amount of friction necessarily transmitted. The more heat we allow the end of the screw shaft to generate, the more power we lose. The dynamical and modern theory of heat is, that heat is *motion*, and therefore the more heat we allow to waste or develop at the end of the shaft, the more motion we lose.

The thrust of the shaft, or the reaction of that force which pushes the ship through the water, is received on a series of metal discs completely immersed in oil. Several discs are employed to distribute the friction, and should two or more set fast, by two pure
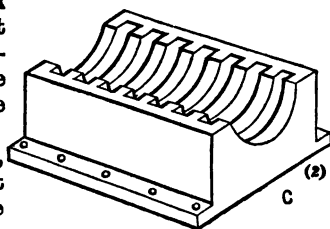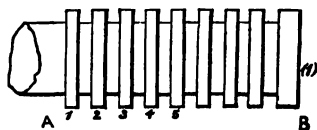
(1) THRUST END OF SHAFT.
(2) LOWER END OF THRUST BLOCK.

metallic surfaces coming in contact, others may be still free to move. By far the best arrangement for receiving the thrust consists of a long plummer block, having in it a series of circular depressions with a square section, into which fit a series of collars turned on the end of the shaft.

A B is the end of the shaft; 1, 2, 3, 4, 5, etc., are the collars turned on it. These fit into the plummer block C. This figure C is a representation of the bottom half only of the plummer block. The cap, which is removed, is similar in section, and contains the corresponding semicircular spaces to fit the collars. The plummer block is hollow, water circulating within.

121. Thrust of Screw—Continued.—If two pieces of lead have their pure metallic surfaces laid bare, and are then put together with a slight pressure and twist, they unite and become almost as one piece ; so will dissimilar metals, as iron and lead, or steel, brass and lead, or even two pieces of steel, or two pieces of glass truly flat and clean. When lead bullets (as they are made at Woolwich, entirely by compression, by driving the dies into the solid lead) are being manufactured, the lead will unite to the steel die, unless oil or grease be employed to interpose between the two metals : the *pure metallic surfaces* unite under pressure by the power of·cohesion. Before the thrust of the propeller was received on a thrust block, as indicated above, it was received on a fixed piece of steel, against which the shaft directly worked. After wear, when the oil had been worn off, and the two surfaces had scraped each other so as to present mutually to one another pure metallic surfaces, the two perfectly united, and united so firmly that the shaft twisted and broke, not directly where the thrust was received, but elsewhere.

122. Area of the Blade.—The area of the blade means the surface acting upon the water, it is generally expressed in square feet. Its resistance offered to the water depends not alone on the surface, but upon the angle of the thread and the diameter of the screw from which it is cut.

123. Soft Metal Bearings.—Soft or white metal is

put into bearings to lessen the friction. It consists of an alloy in many different proportions; one of about two parts of tin, two of antimony, and one of copper answers very well. It has been found an effectual remedy for hot bearings, and wears away very much less than would be expected; but if it be not effectually confined in the brass, it is liable to be forced out, or to "flow out" owing to its softness. In locomotives it has been used successfully in the axle-box, and in the bearing at the large end of the connecting rod, and sometimes in the coupling rod. The bush or brass to be lined with it, is cast with a receptacle for the soft metal, and is then properly prepared, and the metal is attached to it by being poured upon it in a molten state. Frequently such composition is called Babbit's metal.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. What is the nominal horse-power of a pair of engines (1867)? Given:

Diameter of cylinder .... 60 inches
Stroke of piston.................. 5 feet 4 inches
Number of revolutions......... 38.   *Ans.* 243·2.

$$\text{Nominal H.-P.} = \frac{60 \times 60 \times 5\frac{1}{3} \times 2 \times 38}{6000}$$
$$= 243 \cdot 2$$

2. The pitch of a screw is 20 feet, it makes 40 revolutions per minute; find the speed of the ship in knots.

$$\text{Speed} = \frac{20 \times 40 \times 60}{6080} = 7 \cdot 9 \text{ nearly.}$$

If the slip is 10 per cent., find the speed.
As $100 : 7 \cdot 9 : : 90 : 7 \cdot 11$

3. What is meant by the nominal horse-power of an engine, and how is it determined for paddle-wheel vessels (1868)?

4. Describe the common screw-propeller. Define the terms pitch, length, and angle of the screw, and slip. A ship is required to steam at the rate of 12 knots, and the engine crank is to make 76 revolutions, what must be the pitch of the screw if 20 per cent. be allowed for slip (1868)?   *Ans.* 20 feet.

These 12 knots represent the speed of the ship, which is less than that of the screw ; 20 per·cent. or $\frac{1}{5}$ has been taken off the 12 knots, therefore the 12 represents $\frac{4}{5}$ $\therefore$ $\frac{5}{5}$ = 15.

$$\therefore \frac{\text{pitch} \times 76 \times 60}{6080} = 15$$

$$\text{pitch} = \frac{15 \times 6080}{76 \times 60} = 20$$

5. Describe the screw-propeller.   Define the pitch and length of a screw-propeller.   How is the thrust of the propeller received upon the vessel (1869)?

6. Describe some form of engine adapted for driving a screw-propeller.   Define the terms pitch and length, as applied to a screw-propeller (1870).

7. Define the screw-surface, and the pitch and length of a screw-propeller.   Describe the general arrangement of the boilers, engines, screw, shafting, and propeller in a vessel.   How are the engines relieved from the thrust which propels the ship (1871)?

CHAPTER VIII.

BOILERS AND BOILER GEAR.

THE boiler is the vessel in which steam to drive the engine is generated. It has received various shapes from early and late engineers, such as haycock or balloon, waggon, sphere, hemisphere, ring or annular, flue, Lancashire, Cornish, return-tubular, Field's, etc. The early boilers were very defective in their construction, being actually made of cast iron with leaden or wooden tops, and even with wooden shells hooped like barrels, and often with flat surfaces—the weakest of all forms; but then no danger arose, for the pressure seldom or never exceeded twelve or fifteen pounds on the square inch; but now, when boilers have to submit to ten or twelve times that strain, care, thought, and diligent enquiry are absolutely necessary.

If, in the construction of steam boilers, strength alone were studied, the spherical form would be adopted, be-

cause it is the strongest of all forms in which a vessel can
be made if it is to resist either internal or external pres-
sure; but although such boilers have been used here and
there they will never come into extensive use, because
they have not a large amount of heating surface. The
cylindrical form is next to the spherical in point of
strength, and superior to it in respect of superficial area
or heating surface, hence this form is very generally
adopted.

124. Flue or Cylindrical Boilers (external pressure).—
These approach the true shape of a truly efficient boiler.
They consist of a large cylinder with one or more flues
passing through their whole length, which are generally
built of plates of the same thickness as the other parts of
the boiler, but experiments prove this to be a vicious
system.

Flue boilers assume many different arrangements as
regards the flues. This figure shows the return flue boiler.
At first the flue went right through, the fireplace at one
end and the chimney at the other. It was a great
improvement, and early introduced, to let the flue curve
round at the further end and return to the front, so that
chimney and fireplace were both at the same end. The
fireplace is seen to the left, and the chimney on the right
of the front, while the dotted
lines show the course of the
flue in the boiler.
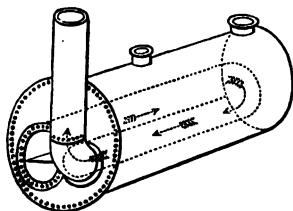
When the boiler has but
one tube running from end
to end, it is generally called
a Cornish boiler, and when
two it receives the name of
Lancashire boiler; but we

RETURN FLUE BOILER.

have explained a little fur-
ther on with an illustration the real distinctive features
of a Cornish boiler, and it must not be left unstated that
we may speak of a two-tube Cornish boiler; but still it
is a very common mode of distinguishing boilers of one

'and two tubes from each other, especially in the Midlands,
calling them respectively Cornish and Lancashire boilers.
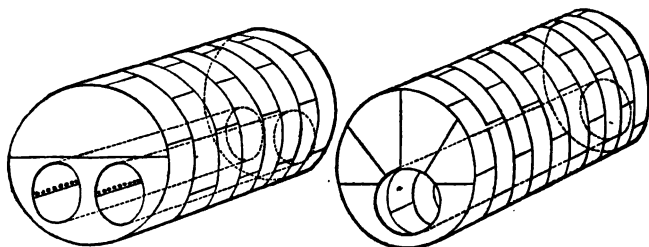
LANCASHIRE BOILER.   CORNISH BOILER.

125. **Length of Flues.**—Sometimes flues are made to
run the whole length of the boiler, twenty or thirty feet,
without any supports. Three tubes were taken, four
inches in diameter, of the same thickness of iron, sup-
ported at the ends by rings, but respectively nineteen,
forty, and sixty inches long. Pressure was brought to
bear upon them, and they collapsed at 137, 65, and 43 lbs.
on the square inch. This clearly demonstrates that the
strength of similar tubes to a collapsing pressure, is in
inverse proportion to their length. Two boiler flues,
forty-two inches in diameter, three-eighths of an inch
thick plate, and twenty-five and thirty-five feet long,
collapsed—the former at a pressure of 97, and the latter
at 27 lbs. on the square inch.

126. **Diameter of Flues.**—The greater the diameter of
a flue or cylindrical boiler, the weaker it is. Its strength
varies inversely as the diameter, i.e., double the diameter
the strength is diminished by one half. From experi-
ments: three five-feet tubes, four, eight, and twelve
inches in diameter, about $\frac{1}{22}$ of an inch in thickness,
collapsed at a pressure of 43, 20·8, and 12·5 lbs. on the
square inch respectively.

127. **Thickness of the Plates.**—The *strength of the flue
is* augmented with the thickness of the plate in a little

greater proportion than the square, *i.e.*, if a plate one-eighth of an inch thick bear a certain strain, then one double the thickness, or one-fourth of an inch thick, will bear a strain $= 2^{2 \cdot 1 \cdot 9}$ or more than four times as great. The greater the diameter of a tube the weaker it is, and because, also, the strength of a plate increases with its thickness, therefore the thickness of a tube plate should be in proportion to the diameter of the tube, or the plates of a two feet diameter flue should be, within certain limits, double the thickness of those of a one foot flue, or, if the plates of a one foot flue are one-fifth of an inch thick, those of a two feet flue should be nearly two-fifths of an inch thick.

Mr. Fairbairn, to whom we are indebted for these important experiments, and from whose valuable work, *Useful Information for Engineers*, these facts are culled, proposes a remedy and modification in tubular boiler tubes, which have hitherto been constructed without a correct knowledge of the laws of nature. He proposes that strong rings of T or angle iron shall be riveted at intervals of 10 feet or less along the flues, thus practically reducing them to several tubes of short length, and, therefore, considerably increasing their strength. He also proposes that they should not be formed with the usual *lap joints*, but with riveted *butt joints*, and longitudinal covering plates.

128. Boilers' Internal Pressure.—The tensile strength of a boiler plate is nearly the same whether torn asunder in the direction of the fibre or across it; and heat does not affect their strength up to 315°C., above which they rapidly become weaker. Riveting reduces the tenacity of a boiler, or the bursting pressure, from 23 tons per square inch to 15 tons. Cylindrical boilers made of the same thickness of plates throughout, are more liable to give way along the sides than at the ends.

The external shell of a boiler is three or four times stronger than the flue, if both are constructed in the

ordinary manner; or, the outside shell more easily resists
the bursting pressure than the tubes the collapsing.
But if the flues are divided into lengths of 10 feet or less
by strong ribs of angle iron, their resistance is enormously
increased.   Cylindrical boilers must be strengthened in
the same way, but are considerably weakened if made
elliptical instead of cylindrical.   The tube of a boiler is
made in several small lengths by bending the plates over
into a circle overlapping along the edges and welded ; the
short tubes are joined together by rivets to corrugated
hoops, or between any two ends is a small ring consist-
ing of two flanges with a small arch between; the flanges
are riveted on to the tubes.

129. **The Marine Flue Boiler.**—In this boiler the fire-
places are within the shell, and the flues wind backwards
and forwards until they discharge the remaining heat up
the funnel, the furnace (or furnaces) being at the end of
the boiler, below the middle of the water.   The heat
first descends to the bottom of the boiler and towards the
farther end, it then winds back towards the furnace, and
turning up and back comes now to the bottom of the
funnel, near the centre of the boiler.

130. **The Marine Tubular Boiler.**—In tubular boilers
the heat is allowed to pass into and through a series of
tubes which run through the water.   They are chiefly
employed in locomotive and marine engines.

The figures on next page represent (1) a longitudinal
section of a marine tubular boiler ; (2) a front view
—partly in section, to give a better idea of it—and show-
ing four furnaces F P, with the ashpits A P.   The small
circles represent the ends of the tubes, W W is the water
in the boiler, w w w the water around the tubes, the spaces
between them are the tubes themselves, w L is the water
level.   In the left hand figure F P is the fireplace, B the
bridge.   The coal is first thrown on to the dead plate D to
warm, it is then pushed on to the fire bars *a a.*   The fire
bars are in lengths, and the ends are not close together,
to allow for expansion.   B the bridge is to prevent the

fire from getting too far back in the furnace; the bridge
sometimes forms part of the boiler itself—a very bad
practice—but is more frequently built of Stourbridge
fire-clay bricks. The heated air and gases pass over the
bridge through the lower tubes *cccc* into the fire box F B,
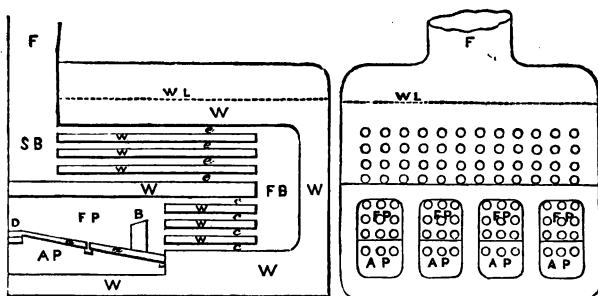
1. *Longitudinal Section.*   2. *Front Elevation.*

TUBULAR BOILER.

then through the tubes *eeee* into the smoke box S B, and
up the funnel or uptake F. The smoke box has a door
opening into the engine room, that the tubes may be
cleared out should soot, etc., lodge in them. They also
slant a little—the short ones towards the fire box, the
longer ones towards the smoke box—that the heat may
receive more resistance in passing through, and have
a better chance of communicating its motion to the water.

   The next figure is another form of marine tubular
boiler which has been much used in compound engines.
The boilers just described are not constructed to bear a very
great pressure of steam, but those on this principle are.

   In this figure the references are the same as in the
last. F P is the fireplace or furnace, A P is the ashpit,
W the water, w L the water line, *c c c c* the tubes, F the
funnel—the bottom of which in this arrangement answers
both for firebox and smoke box. Each fireplace has its

own boiler, which can be kept perfectly distinct, as will·
be explained when speaking of the communication valve.
A B is the superheating apparatus; the steam leaves the
steam chest by the passages *a a*, and passing in and out
through the tubes within A B becomes further heated
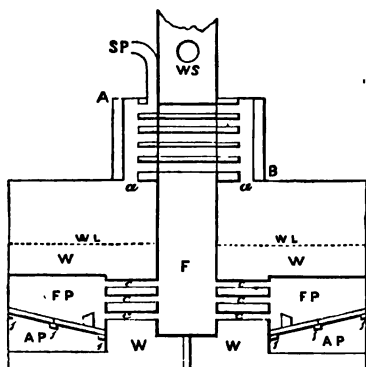
SECTION OF MARINE BOILER.

by the heat passing up the funnel, and is carried off by
the steam pipe S P to the cylinder. At W S the waste
steam returns through the exhaust pipe, and rushing up
the chimney creates a draught, answering better than a
blast, and giving the engine-maker a chance of making
his furnace small.

131. **Vertical Boilers.** — Vertical boilers assume
many shapes internally, although their outward appear-
ance corresponds very much to the following figure.
Vertical boilers are used in steam cranes, hoists, and
often in portable engines, and in Samuel's express
locomotive. In this figure F B is the fire box; the
letters W W show the water spaces, w L the water
line. It is seen that tubes leave the boiler immediately
above the fireplace, and rejoin the water at the crown of
the furnace. Evidently, from this arrangement, the

convected water will have a free rise, and a given quantity of heat will produce a fair amount of evaporation. In vertical boilers vertical tubes are used, as in Samuel's locomotive mentioned above; but vertical tubes by no means constitute a vertical boiler.
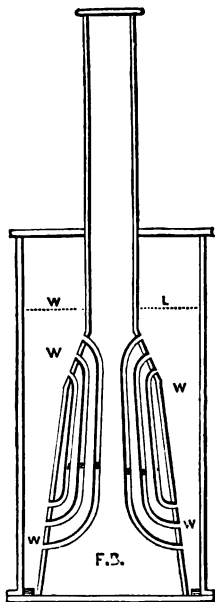
The **Blast Pipe** is a pipe leading from the boiler into the funnel to create a draught while getting up steam; but when the engine is moving (noncondensing engines), the waste steam passing through the waste steam pipe performs this office. The steam rushing up the funnel leaves behind a vacuum, when the air, rushing through the fire bars to supply its place, gives up its store of oxygen to combine with the other products of combustion, and intense heat is produced. It was this contrivance that so efficiently assisted Stephenson to win the prize of £500 at the memorable competition at Rainhill, when his engine, the "Rocket," now in the South Kensington Museum, defeated the "Novelty" and "Sanspareil." He also used coke and a tubular boiler.

VERTICAL BOILER.

. **132. Waste Steam Pipe.**—The waste steam pipe is placed immediately over the safety valves to carry off the waste steam; it runs up by the side of the funnel, and has frequently a *steam trap* at the top from which a drip pipe runs to carry off whatever may have accumulated in it.

The **Steam Chest** is either a dome above the boiler, or else the upper part of the boiler. It is a reservoir for steam, and should the engines be using steam faster than the evaporation of the boiler, there is a supply to fall back upon.

133. The Cornish Boiler.—The Cornish boiler is a long cylindrical one. Its peculiarity is in the internal arrangement of the flues, which can be best understood by well examining the annexed figures.
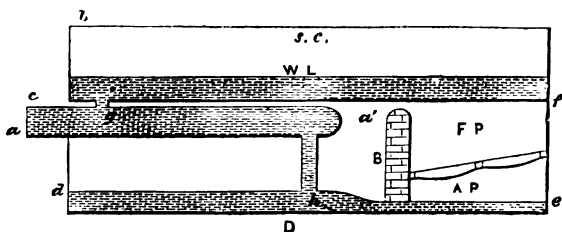
Longitudinal Section.

CORNISH BOILER.

D is a longitudinal section, E a cross section. The lines of shading in both figures show the water. *c d e f* is the flue, in the right hand of which is the fireplace and ash pit. Immediately behind the fire bridge B is a large tube *a' a* running beyond the end of the boiler to *a*, and suspended within the flame and burning gases. It communi-

Transverse Section.

cates with the rest of the boiler at *g* and *h* by means of two copper pipes. Sometimes the pipe is not at *g*, but leads from the end *a* into the top of the boiler at *b*. W L is the water level, and it will be observed that there is a very large steam chest *s c*, and that the surface of the water is large. It is for this reason that there is no priming in Cornish boilers—the steam having plenty of room and a large surface to rise from. The fire and heat play everywhere within the flue, and are brought right round under the boiler, and pass along by D to heat the water in the bottom space *d h e*. The whole is set in masonry, and the arrangements are so good that very little heat can escape by conduction

or radiation, while the heating surface is very great. From having such a large amount of heating surface, it has been calculated that a pound of best Welsh coal, in a Cornish boiler, will evaporate 11½ lbs. of water.

134. Staying of Boilers—Boiler Stays.—Boilers are stayed to give them additional strength. In cylindrical boilers a few stays run from end to end for support. Any flat part of a boiler must be stayed; it is generally found better to use a number of small stays than three or four large ones. The furnaces in marine boilers should always be stayed by means of these. The staying of boilers is a matter of vital importance.

Boilers are generally fitted with man-hole and mud-hole doors. The *man-hole* is frequently in the top of the boiler, and is fastened on with bolts and nuts. Its purpose is to give ingress to the interior of the boiler, so that any necessary repairs may be made. The *mud-hole door* is fitted in the bottom to allow of the boiler being easily cleansed from accumulation of mud, salt, etc. This particularly applies to marine boilers, and boilers in river steamers. The mud-hole door should be fitted on *inside*, and the heads of the bolts *inside*, and the nuts outside. Through inattention to these points several accidents have happened. The nuts have become loose and the mud-hole door given way, when the whole body of water and steam have been driven into the engine-room and the men scalded to death.

135. Clothing of Boiler.—Instead of boilers being allowed to come in direct contact with the brickwork around them, they are embedded in some non-conducting substance, as wood, fine cinders, etc., so that a minimum amount of heat may escape by conduction from the boilers. For the same reason, cylinders are clothed and jacketed, while the top of the boilers are frequently covered, *i.e.*, clothed with wood, haircloth, etc., and painted to prevent radiation.

136. Copper Boilers.—Copper boilers are considered by some more efficient than iron boilers; their first cost being so very much greater than those of iron, they

have not been used to any great extent. Copper being a better conductor than iron, the heat more readily passes into the water, and consequently there is more economy exercised so far as heat is concerned. They are not quite so strong as iron, in the proportion of 16 to 23, but they do not waste by scaling; and, therefore, they retain their original strength for a long time, while the iron ones are continually getting weaker and weaker. In consequence of its great conductibility and not wasting and burning at the joints, it is used for the furnaces of locomotive boilers. Copper is seldom used now for boilers, as experience has taught that they are not quite so efficient as might have been expected. It is soon damaged in the furnaces by the use of sulphurous coal, and when a leak appears it rapidly becomes weaker in the neighbourhood of the leak.

137. **Funnel and its Casing.**—The funnel is the chimney of the marine boiler. It consists of two parts, (1) the *funnel*, (2) *the casing*. The *funnel* is made of large plates of iron, and all the waste products of combustion are carried up them into the air. They must not be too wide, or the draught is not sufficiently strong. A rule is sometimes adopted in marine chimneys of allowing six square inches of flue section to each horse-power of the engine. In the chimney or funnel is fitted the damper, consisting of two discs, which, when shut down, will allow no draught; they can be raised so as to give any amount of opening, and regulate the draught according to the judgment of the engineers.

Round the funnel, at the distance of a few inches from it, is placed the *funnel casing;* as the funnel gets heated by the gases passing up it, it communicates the motion to the air, which becomes rarefied and ascends. A continual current of convected air is rapidly passing between the funnel and the casing to keep the former cool. Holes are left in the casing near the deck for air to pass in.

138. **Surface Condensation.**—Surface condensation consists in exposing the hot steam to large cold surfaces.

Watt tried it. Hall's surface condensers consist of an immense number of vertical tubes or pipes placed in a large tank. The steam, after being used in the cylinders, passes through these pipes. Water surrounds the tubes, and is forced through the tank in among the tubes, either by pressure from behind or by creating a vacuum in front. The cold water enters at the opposite end to the steam, and goes out at the end where steam enters; thus the hot steam meets the warmer water first and the colder last, by which arrangement the water is made to carry off as much heat as possible.

139. Appendages to the Boiler.—The necessary appendages to a boiler are the safety valve, the gauge—which may be the old fashioned mercurial gauge—Salter's spring balance, or Bourdon's gauge, the reverse valve, the glass water gauge, or else gauge cocks.

The *safety valve* is a lever of the third kind, the fulcrum at one end, the weight at the other, while the power is exerted between the two.

It is a conical valve, fitted steam tight on its seat, and kept down by a weight. The weight is so proportioned that when the steam exceeds a certain pressure the valve will lift and the steam escape, and so prevent the boiler bursting, by keeping the pressure below a fixed maximum. Its area varies with different makers, but some engineers follow the rule of allowing half an inch of area to each horse-power of the engine. The weight is fixed by the engine-makers, and no increase should be allowed without their express sanction. Every boiler, when there are two or more to the same engine, must have its own safety valve. Some safety valves are kept on their seats by spiral springs.

140. Salter's Spring Balance is used especially in locomotives to exhibit the pressure of steam. Its principle is a steel spring, well tightened, which, according to the pressure of steam, extends after the manner of the spring steel yards used in public by our rag and bone merchants; or else the increased pressure of steam acts against the spring.

An adaptation of the spring balance to safety valve is shown by the figure in the margin, where A is screwed into the boiler, or into a pipe in free communication with the steam, so that steam can enter the cylindrical body B ; if we suppose the dotted lines at A form a piston, it will act against it to drive it down, which the pressure of the spring will not allow it to do until it overcomes its resistance. The greater the force of the steam the more will the spring be compressed, and the more of the graduated part be shown. Acting on this principle it is evident that, if it be properly graduated, the pressure of steam in the boiler will be correctly indicated by the scale. When used to keep down a safety valve, it is evident that the piston must open a vent at a certain point of its stroke, or else the valve must be able to rise considerably on its seat before steam can escape ; this is the exceptional arrangement, as Salter's spring balance is used in a simpler manner for a *pressure* gauge, and not to keep the safety valve on the seat.

141. Bourdon's Gauge.—This gauge is produced in many shapes—we give one of the most portable and convenient in the figure on the next page. A B is a circular plate, fitting steam tight in *s*, but still readily moving with the least pressure. *s* is in free communication with the boiler, by way of E ; therefore the pressure of steam below will cause the plate to ascend, when the rod *r* will move the lever *a b* on its centre *b*, and with it the rack *c d*, which moves the pinion *p* from right to left, and with it the pointer P, which will indicate the number of pounds pressure in the boiler on the arc.

The use of gauges, it will be gathered from what precedes, is (1) to tell *accurately* the pressure of steam in boilers when water is hotter than 100° C. ; (2) to indicate the *variation*
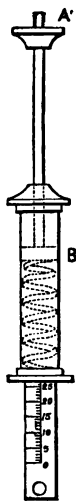
SPRING BALANCE.

in the pressure of steam from time to time. When we consider how much depends upon a knowledge of these facts, the following instance of—to say the least— carelessness and thoughtlessness will astonish us :—Out of 52 gauges tested for the Royal Agricultural Society, upon the occasion of their exhibition being held at Manchester, only nine were correct. If this be a fair average, the deplorable fact comes to light that only 17·3 per cent. of the gauges in common use give correct indications of the state of the boiler pressure.

142. **Vacuum Gauge.**—The same figure will illustrate the vacuum gauge and its principle. The vacuum gauge is to show the state of the vacuum in the condenser, and so is an appendage to the condenser and not to the boiler.

E is fitted into the condenser. If A B be air tight, there being a vacuum in the condenser, when the cock V is opened, the piston will *descend* by reason of the pressure of air above it. If the pointer be directed to a particular point when the air is acting freely on both sides of the piston A B, then, as the vacuum increases in the condenser, the pointer will move from left to right. When the gauge is used to show a vacuum the graduation only extends from 1 lb. to 15 lbs. The teacher must accustom his pupils to draw the figures clearly, pointing out the difference of action, when used as a vacuum gauge and as a steam pressure gauge.

BOURDON'S GUAGE.

143. **Communication or Stop Valve.**—The purpose of the *communication* or *stop valve* is to allow the steam to pass from the boiler to the engine. When it is wished to start, a handle is turned round, which lifts generally

an ordinary conical valve from its seat, and the steam passes at once into the steam pipe to the slide casing, etc. A communication valve is fitted to each boiler, so that when an engine has several boilers, any one or more can be used without the other. The *regulator* in the locomotive corresponds to the communication valve in the marine and land engine.

144. Glass Water Gauge.—The best contrivance to ascertain the height of the water in the boilers is the glass water gauge; whereby, at a glance, the engineer can see the height of the water. Gauge cocks are also used; they consist of three ordinary cocks— the lower one placed below the level of the water, and from which water should al- ways flow when it is turned; the middle on a level with the water, from which steam and water should issue; and the third above the level of the water, from which steam should always issue when turned. To bring the gauge cocks within reach of the engineman, they are placed low down or in a line, and tubes lead up inside the boiler to the required heights, and to a part of the boiler where the ebullition is least.

The figure will exhibit the principle of the glass water gauge, which is often carried out by a more elaborate system of cocks to prevent the gauge from choking, and to clean it out. W is the water in the boiler, and w l the water line, A B the glass gauge in communication with the
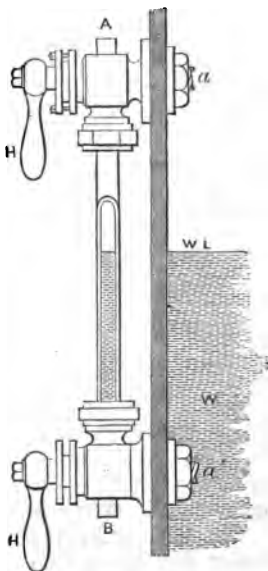
GLASS WATER GAUGE.

boiler at a and a'. It is seen that the height of the water in the gauge will show the level of the water in the boiler, and whether it be necessary to continue or discontinue the feed water. There are cocks at the two ends A and B, as well as at H and H, to clean out the gauge.

145. The Reverse Valve — *Vacuum Valve, Internal Safety Valve,* or *Atmospheric Valve*—for it has all these names—is to prevent the boiler from collapsing through the external pressure of air. When a boiler has been in use, we will suppose the engine stops, and that the stop valve, safety valve, etc., are closed. Then, as the water cools down and steam condenses, a vacuum will exist in the boiler; and if means are not taken to prevent the external pressure of 15 lbs. on the square inch from taking effect, danger will ensue to it. A B shows the general appearance of the valve, S leads to the boiler. The air pressing upwards in the direction of the arrows will lift up the valve V and open it, when the internal pressure is at a certain stage below that of the atmosphere ; then passing into the boiler through S, will restore equilibrium, or, at least, partial equilibrium. It is generally made of such a weight that it will lift with an external pressure of 5 lbs. The pressure in the boiler can get below that of the atmosphere when the supply of steam is insufficient for the engines (if there be a good vacuum), or if a sea were to break over a ship and suddenly condense the steam in the boiler.
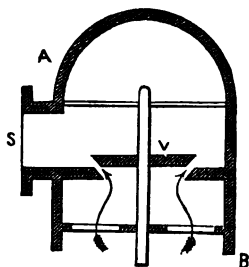
REVERSE VALVE.

146. Boiling Point of Sea Water.—An analysis of sea water has been given on page 33. In consequence of some of the solid substances being chemically combined, and the others mechanically suspended in sea water,

especially because of the latter, and its specific gravity being greater than fresh water, it takes considerably more heat to boil it than to boil fresh, spring, or river water, and of course, as ebullition continues and the steam is used, the water will get salter and salter; no salt can possibly pass away with the steam, and therefore the amount of heat required to convert the water into steam will have to be increased in proportion to the density of the water, while the water itself will become saturated with salt, or it will be incapable of holding more salt, which will be precipitated and form a crust on the boiler, separating the iron boiler plates from the water: thus the boiler plates can actually become red hot, and danger is imminent; for, the plates being softened, they are liable to collapse.

147. Boiling Point of Salt Water.—Salt water containing $\frac{1}{30}$ part of salt (it has been usual in all works on steam to say $\frac{1}{33}$), will boil at a temperature of $100°\frac{2}{3}$ C.; if the proportion of salt be doubled or $\frac{2}{30}$ it will boil at a temperature of $101°\frac{1}{3}$ C., if $\frac{3}{30}$ or $\frac{4}{30}$ the boiling point will rise respectively to $102°$ C. and $102°\frac{1}{3}$ C.; when there are $\frac{12}{30}$ of salt in the water, the boiling point rises to $107°\frac{7}{9}$ C. $\frac{12}{30}$ is the point of saturation, when the water is so full of salt that it will hold no more, and it is therefore rapidly precipitated. It will assist the memory, perhaps, to state that in each gallon of sea water there are more than four ounces of salt, and if two gallons be boiled down to one, it will contain double that amount, or more than eight ounces.

148. Blowing out or Brining the Boilers.—Generally the saltness of water in the boilers must be kept below three or four-thirtieths. To effect this, and to have them as free from salt as is consistent with the economical consumption of heat, the practice of "blowing out" is resorted to. For the purpose blow out cocks are fitted to the bottoms of all marine boilers, and from the cocks pipes lead into the sea. Every two hours, but generally less, the blow out cocks are opened, and the supersalted water violently forced out of the boiler, by the pressure of

the steam, into the sea.   Much heat is lost by this blowing out, and many methods have been devised to save it.   Before showing how this is accomplished, we must give other modes of getting rid of the impurities which collect in a marine boiler.   The brine is sent overboard,

    (1) BY BLOW OUT COCKS (already explained).
    (2) BY BRINE PUMPS.
    (3) BY SURFACE BLOW OUT AND SCUM COCKS.

149. (2) By Brine Pumps.—To many engines are fitted brine pumps, which at every revolution of the engine extract a small portion of brine from the boiler.   The size of the brine pumps must be such that the quantity of water drawn off, added to that evaporated, shall be equal to the quantity introduced by the feed pump.   If the water ejected from the boiler is to contain $\frac{3}{80}$ of salt, or three times as much as the feed water, then, if the feed pump supply n gallons in a given time, the brine pumps must extract $\frac{n}{3}$ gallons in the same time.   The rule is, blow out from $\frac{1}{4}$ to $\frac{1}{3}$ the amount of feed water.

150. (3) Surface Blow Out and Scum Cocks.—The foreign substances in a boiler are always buoyed up to the surface, where they not alone prevent ebullition, but the formation of steam.   The steam rises from and around them, and they remain at the surface for some time, when they gradually descend and form a scale upon the tubes and flues.   It is therefore found quite as advantageous to blow out from the surface as from the bottom of the water.   It is done by means of **scum cocks,** which are inserted on a level with the water, and are kept constantly about one-eighth open the whole of the time, so that as fast as dirty scum and other impurities rise to the surface they are expelled.

151. Kingston's Valves.—Every orifice in a ship's bottom should be fitted with one of these valves.   The hole in the bottom of the ship into which one of these valves is fitted is conical and larger on the outside than on the inside.   The Kingston valve, likewise conical, corre-

sponds to the opening, so that when it is screwed up the pressure of water outside, on the larger end of the cone, tends to tighten it and keep it in its place. They are liable to set fast on their seat, hence one of the duties of the engineer is to frequently test them to see that they do not stick.

152. Salt and the Boiling Point.—There are several methods of ascertaining the amount of saturation of the water in a marine boiler :—

> (1) By the THERMOMETER.
> (2)   „   HYDROMETER.
> (3)   „   SALINOMETER.

From what has been said it will be gathered that the boiling point of water depends upon the quantity of salt in it and its specific gravity.   The strength of a solution of salt and water has always a fixed and well ascertained relation to the boiling point and specific gravity.

For water with

$\frac{1}{30}$ or	1° of saltness in it boils at			100°$\frac{2}{3}$C.
$\frac{2}{30}$ or	2°	„	„	101°$\frac{1}{3}$C.
$\frac{3}{30}$ or	3°	„	„	102° C.
$\frac{4}{30}$ or	4°	„	„	102°$\frac{2}{3}$C.
$\frac{5}{30}$ or	5°	„ .	„	103°$\frac{1}{3}$C.
$\frac{10}{30}$ or	10°	, „	„	106°$\frac{1}{6}$C.
$\frac{12}{30}$ or	12°	„	„	107°$\frac{7}{6}$C.

And also as fresh water when the barometer stands at

27 inches boils at a temperature of				97°·2C.
28	„	„	„	98°·1 C.
29	„	„	„	99°·1 C.
30	„	„	„	100° C.
31	„	„ .	„	100°·8C.

we see at once the truth of what was said above, that the boiling point of water depends upon its weight or specific gravity and the pressure of the air.

If, then, water be taken from the boiler, and boiled in the engine room under the ordinary barometric pressure of the air, and it is found by using the thermometer that its temperature at the boiling point is 103°$\frac{1}{3}$C., we must

at once conclude that there are 5 degrees of saltness in the water, and that salt is being precipitated, and blowing out must be resorted to at once. But if by the same process it is ascertained that the water boils at 101°⅓C. (in the engine room), it is known that the boiler is comparatively safe and in good working condition.

153. The Hydrometer tells us the amount of salt in water by showing its specific gravity. The figure in the margin represents one. B is a hollow ball of brass or other metal, from which rises a stem C D, graduated; A is a second globe filled with mercury to make the whole swim uprightly in the water. A acts in precisely the same manner as the lead on a fishing line. The lead keeps the float upright, so does A the hydrometer.
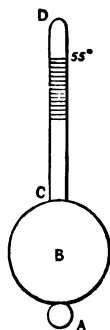
The stem C D is graduated that we may read off how far the stem sinks in the water. The greater the specific gravity of the water, or the more salt there is in it, the *less* it will sink, so the density is thus made a test to exhibit the amount of salt. We read off (not the density, but) the saltness of the water. Each hydrometer is graduated to a particular scale, generally 55°; *i.e.*, when placed in distilled water at a temperature of 55° the hydrometer sinks to the point marked 55°. This is much too low, for when water is taken from the boiler, the experimentalist has to wait a considerable time for the water to cool down before he can test it. 90° C. would be a far better temperature to select. Thus we see the hydrometer is an imperfect instrument without the barometer; so useless is the one without the other, that we frequently see attempts made to combine the two, as in the *salinometer*.

HYDROMETER.

154. Salinometer.—The salinometer has been presented in several shapes. In one it consists of a thermometer and hydrometer combined in a copper vessel; in another, Seaward's salinometer, of two pith balls. Mr. Seaward

affixes a glass tube fourteen inches long, in a similar manner and in a corresponding place to the glass water gauge, so that when attached to the boiler the water rises up from the bottom of the boiler through the lower cock, and remains in the glass tube at the same level as the water in the boiler. The taps are then closed and the upper one opened, and two small balls of glass or metal are dropped into the water. The specific gravity of the first ball is such that it will sink when there are five degrees of saltness in the water and swim when there are more, the other ball will sink when there are less than three degrees of saltness, but swim when four or more. By this method the state of the boiler is soon ascertained.

155. **Scale.**—Whatever care and precaution are adopted, scale can hardly be prevented from forming on the boiler plates. A careful and attentive engineer can always reduce it to a minimum. When scale is formed on the boiler plates, it prevents the passage of heat into the water, for salt, gypsum, lime, etc., are exceedingly bad conductors of heat, and will not allow its motion to pass to the water, and therefore a waste of fuel must arise. When water is saturated with salt, etc., through negligence or otherwise, it becomes heavier, and therefore takes more heat to boil it, which is another waste of fuel; again, the scale is occasionally so hard and solid that the plates become red hot, and are liable to be burnt as well as to give way from internal pressure. Ammonic chloride and other chemical substances are sometimes put into marine boilers to prevent scale, but the utmost they do is to precipitate the foreign ingredients as powder, which must still be removed by blowing out. The more of these substances there are in the water, the more work the heat has to do to lift them, and therefore the more heat is required for ebullition, which is waste of motion and power.

156. **Priming.**—When the steam comes from the boiler mixed with water, in the shape of spray or froth, it is said to be primed. Priming exists under most

diverse circumstances; its cause cannot at all times be clearly traced.

157. Causes and Danger of Priming.—Priming takes place more in new than in old boilers; when there is but little water in the boiler; when the spaces between the tubes and flues are contracted; when there is fierce ebullition, this cause may be said to accompany all priming; in passing from fresh water to salt or salt to fresh; when the water used is muddy, dirty, or slimy; *when there is too small a steam chest;* when a safety valve, being situated near the steam pipe, is suddenly opened. The risk arising from priming is very great, and should therefore be most anxiously guarded against. We shall see its danger and injurious effect, if we will but consider that, when it gets into the cylinder, and is there condensed into incompressible water, something must give way should the test cocks and escape valves act improperly. Priming impairs the vacuum; in consequence of this, more water will have to be used for condensation, which will throw a greater load upon the air pump, and more feed water will also be required.

158. Remedy for Priming.—As priming is generally accompanied with great ebullition, obviously the most effectual remedy will be to enlarge the steam chest. It is found that boilers with plenty of water surface, or with a large steam chest, seldom or never prime. Cornish boilers with their large water surface give no trouble by priming. A remedy much practised with locomotive boilers, is to open a safety valve *remote from the steam chest and pipe.* Other temporary remedies are to partly shut the throttle valve; to work the steam at a high pressure; to open the furnace door, thus checking the fierce boiling; to put down the stop valve so that the steam rushes against it, and the water is thrown out; to inject tallow into the boiler by means of the donkey pump or a syringe fitted on purpose, this is the favourite remedy, but it is found in some boilers to increase the priming. Another remedy is to fit a steam pipe full of

small holes in the boiler, and inside this another similar pipe, but to take care that the perforations of one pipe are not opposite those of the other. The steam in entering dashes against the inside pipe, and the spray falls out. Any thing that checks furious ebullition, or allows the steam plenty of space to rise, checks priming. When the steam chest has to be enlarged, it is better to fit a second on the top of the old one. Priming, arising from the use of impure water, may be obviated by liberally blowing off from the surface until the nuisance is abated.

Boilers sometimes prime when the ship passes from salt to fresh water or fresh water to salt. It has been suggested that in passing from salt to fresh water the cause is this : fresh water being lighter than salt, is upon its admission to the boiler more easily thrown about by the ebullition, and therefore more spray is flying ; but as the same boiler will also prime in passing from fresh to salt water, this reason evidently will not hold; we have yet to seek the true cause. May not the change of water cause a serious change in the existing condition of the boiler, and this change being accompanied by a general disturbance of the equilibrium of the water, much more spray is thrown off than usual, and priming follows.* When new boilers have primed, a good plan adopted is to run into harbour and blow out the boiler several times in succession. This has often effectually prevented priming.

159. Feed Pumps.—The feed is supplied to the boilers in one of the following ways: (1) By boiler hand pumps; (2) by the donkey engine; (3) by the feed pump proper; (4) by Giffard's injector.

(1) The boiler hand pumps are fitted to marine boilers, so that when there is no steam up men may fill the boiler by hand, providing it is not sufficiently below the level of the sea for sea water to run in freely when the Kingston valve is opened.

(2) The donkey is a small steam pump in the engine-

* See Causes of Boiler Explosions—Spheroidal Condition of Water, and Water Purged from Air.
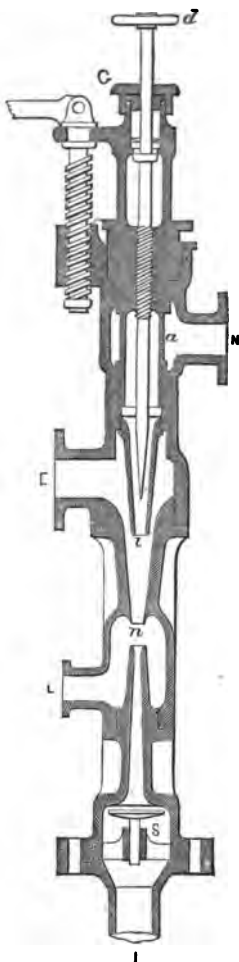
GIFFARD'S INJECTOR.

room that can be set to work to fill up the boilers when the engines are waiting for orders. The donkey has always the steam piston and pump piston at opposite ends of the same rods.

(3) The feed pumps which have been already explained.

In stationary engines part of the warm condensing water is driven into the boiler as feed; the rest, by far the greater quantity, being allowed to run away. But the feed pumps should at all times be capable of supplying much more water than the boiler in its normal state will use. The capacity of the feed pump is generally about $\frac{1}{240}$th that of the cylinder, it can supply more than *three* times as much as is required. While the steam pipe should be attached to the highest point of the steam chest, the feed pipe should be fixed as low down as possible, that the cold water may gradually rise. In Government vessels the feed and donkey pumps are generally made of brass.

160. (4) **Giffard's Injector.** —This is a novel contrivance for feeding boilers, fast superseding all other methods of feed; but no convincing explanation of its action has yet been offered.

We will suppose it properly

attached to the boiler, it then works in the following manner :—

G I is the injector, N is attached to the boiler. Steam can pass into the injector at N. When the handle d is moved up, steam rushes through $a\,i$ at i, where it meets the water supply coming into the injector at E. The steam drives the water through n, and beyond the valve s, into the\ boiler. When there is sufficient water in the boiler, the valve s is forced upwards, and no more water can pass it; the waste water can then pass through the overflow pipe L. The steam to work the injector must be taken from the highest part of the boiler, and must not be primed. The water driven through it may be taken from a cistern overhead, or from a tank in the ground; but the distance from the level of the water below, to E above, must not exceed 5 feet. Now it is found that the pressure of steam will actually drive the water into the boiler, although it has to force it against the pressure of both the *steam and water* in the boiler.

A jet of steam, moving with perhaps a velocity of 1700 feet per second, is instantly condensed in perhaps twelve times its weight of water. The combined jet will then move, by the momentum imparted to it by the steam, at one-thirteenth its former velocity, 131 feet per second—the motion of the steam being wholly imparted to the water. Thus the jet properly directed enters the boiler, and we can find an explanation of the action of the injector by simply considering that it acts solely by the momentum imparted to the water by the jet of steam.

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EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. What is a circular inch? A safety valve seven inches in diameter is loaded to 6 lbs. on the square inch, what would be the load on each circular inch (1867)? *Ans.* 4·7124 ft.

2. What is the usual boiler used for marine engines? Describe it. Why is the arrangement peculiarly useful for marine purposes (1867)?

3. Describe the safety valve. If a circular inch be allowed on the area of a safety valve for every 20 square feet of heating surface, what must be the diameter of a valve for a boiler whose heating surface is 1200 square feet (1868)? *Ans.* 7·74.

4. Describe the safety valve of a locomotive boiler. Explain Bourdon's gauge for ascertaining the exact pressure of the steam in a boiler (1869).

5. Describe with a sketch the marine tubular boiler.

6. What is the object of a reverse valve, and how is it fitted ?

7. How is a vessel protected from the heat of the funnel (1869)?

8. Describe Kingston's valve. Show how to ascertain the degree of saltness of the water in a marine boiler (1869).

9. In the old-fashioned waggon boiler a vertical open tube, called a stand-pipe, passed through the shell of the boiler, and dipped below the surface of the water inside. If the steam pressure inside the boiler were 4 lbs. per square inch, at what height would the water stand in the pipe (1870) ? *Ans.* 9.06 ft.

10. A cylindrical boiler with flat ends is 30 feet long, 6 feet in diameter, and has two internal flues, each 2¼ feet in diameter. The pressure of the steam in the boiler is 40 lbs. on the inch, what is the whole pressure on the internal surface in tons ? How is the strength of a cylindrical boiler related to its diameter, the material being unchanged (1870) ? *Ans.* 2596·95.

11. Describe and explain some form of vacuum gauge which would enable you to ascertain the pressure in the interior of the condenser of a steam engine (1870) ?

12. Describe a method of ascertaining the degree of saltness of the water in a marine boiler (1870).

13. Describe a cylindrical boiler with internal flues. State the advantages of this mode of construction. Which is the weakest part of the boiler, and how is it strengthened ?

14. Sketch the boiler in transverse section with the flues, showing the probable level of the water (1871).

15. Describe with a sketch the glass gauge for showing the height of the water in a boiler. Point out the position and use of the three stop cocks. For what purpose are gauge-cocks fitted to a boiler (1871)?

16. Why is it necessary that some of the hot water in a marine boiler should be continually got rid of and exchanged for water from the hot well? In what way does a thermometer inform you as to the amount of salt contained in the water of the boiler (1871)?

CHAPTER IX.

PRACTICAL WORKING.*

Duties to Machinery when in Harbour and Getting up Steam—
    Starting the Engines — Under Steam — Fires — Bearings —
    Engines in Port.

161. Duties to Machinery when in Harbour before Getting under Steam.—When an engineer takes charge of the machinery of a boat, his first attention ought to be directed to his boilers; for, being the source of power, they may become the source of great danger if not properly looked after. In inspecting the boilers three things require especial notice :—(1) The thickness of the plates above the fires and other places of importance; (2) the state of the stays; (3) the position of the gauges, viz., the water gauge cocks, and glass water gauges.

(1) Respecting the first, a general plan is to drill a small hole through the plate, and thus find its real thickness, for it is often the case that a boiler plate may be far thicker at the seams than in the middle. At the seams the proper thickness cannot always be correctly ascertained on account of the way in which they are caulked, by which a plate may appear considerably thicker than it really is. After the hole has served its purpose, it is tapped and plugged tightly up again.

(2) As regards the stays, they require a great amount of attention, for they are very apt to get eaten through near the plates by oxidation.

(3) The gauge cocks are often placed just above the highest row of tubes. Now this is a very dangerous

* Written by a Working Man.

practice, for it is possible for an engineer to lose his water, let him be ever so careful, when great danger follows; while if the cocks were placed a little higher, the loss of water would not be necessarily followed by so much danger.

162. Duties to Machinery when Steam is Getting up. —The water in the boiler when the fires are lighted ought to be just above the bottom of the glass. In a large, or even moderate sized boiler, the water will expand slightly, and there is also not so much water to heat at first; and we know, by reason of conduction and radiation, that small bodies of water are heated comparatively more rapidly than large. On first lighting the fires they should not be kept too large, but just sufficient to cover the bars. A large thin surface of fire is found to be the most effective on getting under weigh.

When the fires are lighted, and the steamer is going on a long voyage, it is the practice to rub the polished parts of the engine over with a composition of tallow and white lead. This prevents any rust forming on the rods, etc., from water dropping on them which may have been used for keeping the bearings cool.

The discharge valve is also opened now, or else on starting the engine something will give way. Several accidents have occurred by neglecting to do this.

The safety valves are now to be inspected to find out whether they are fast corroded to their seatings. If so, they must be freed and made ready to act before starting.

It is a good plan, and one much practised, to give the engines a good blowing through whilst the steam is getting up. This warms the cylinder, and trys any joints that may have been made since the engines were worked last. It also saves the steam, for if not done now (when the engine is started), a great amount of steam is wasted in heating the cylinder instead of imparting its elastic force to the piston. It is thus that boilers are sometimes taxed beyond their powers, and the steam pressure reduced to perhaps a very dangerous point,

163. Starting the Engines. — All ships are now fitted with the double eccentrics, or Stephenson's Link Motion, by which the engines are started, or rather by this the slide valves are under the command of the engineer, and can be worked back or forward as command be given, by either a bar, lever, or generally, in large engines, by a wheel.

The handle, by which steam is turned on and off, with the injection cock handles, are placed beside the wheel, so that one man can now generally start the engine.

Some large ships have a steam piston so fitted that it rises and falls by steam admitted above or below, thus raising or lowering the link in its motion. This is what is called steam starting gear, and is very handy when the link is of great weight. There is always hand gear fitted as well, which can be used in cases of emergency. In giving injection to a common condenser, it should be opened just after the steam is turned on to the cylinders, or else, if going slowly, the condenser may become too full of water, and the air pump not able to perform its work properly.

In starting an engine that is fitted with surface condensers, the only thing requiring attention before going on, is to open both valves communicating with the sea above or below the condenser, viz., suction to the circulating pumps and delivery from them.

DUTIES WHEN UNDER STEAM.

164. The Boiler.—Continually look at the water level in the glass gauge. This is oftentimes a source of great anxiety, for some boilers require the water to be kept at a certain fixed level. If water be too high they will not keep steam, and if too low the steam will generate too fast. Some boilers require a high water level, others a low one; in fact no general rule can be given for the water level, nothing but practice can determine it. A safe rule is to keep the glass water gauge about two-thirds full.

The fires require much consideration. A furnace is

best worked with a heavy fire, but not too heavy, thicker towards the back than front. The fresh fuel should be placed in front, and then pushed back after being thoroughly heated. Every four hours (at the least) the fires should be cleaned out, as large clinkers or refuse of the coals adhere to the fire bars and prevent the draught, making the fires burn dead, especially towards the back of the furnace. Sometimes the slag will stick fast to a furnace bar, and cannot be removed from it. This causes a great amount of trouble, as in trying to remove it the fire bars are occasionally pulled out of their places, and the greater part of the fire falls through, causing much waste and often danger.

The principal thing to pay attention to when the engines are under steam, is to keep the bearings cool and the glands steam tight. Oil is generally used for keeping bearings cool, but when larger ones are working hard, a jet of water is kept playing upon them. This is found to answer very well when the water is turned on before they have had time to heat. It should not be used after they have been allowed to get heated, for it may crack them by too sudden contraction. A good stream of water should be kept running on the thrust block from the time of starting, this with the tallow, which is always put into it before starting, keeps this all-important bearing cool. The cap of the thrust block requires great care in adjusting. If screwed on too tightly it is almost sure to heat or fire, as it is termed, and if not screwed down sufficiently tight, the unpleasant jumping shake, so often experienced in our screw ships, is sure to follow.

In new fast running engines, castor oil is a very good thing to use on first starting. When new brasses have been fitted into the bearings, till they form a good bearing for themselves, the same should be used. It appears to have a much firmer body in it to lubricate than all other oils have. The difference in the cost of the oil is not very much, coarse castor oil being very little dearer than good machine oil,

165. Duties to Machinery when the Ship has Arrived in Port.—The white lead and tallow should be rubbed off with a piece of oily waste, and then the bright work of the engines will give no trouble by rusting.

The engines should have a good blowing through to drive out all water in the condensers, then the Kingston's valves, communicating with the sea, should be shut, next open the condenser drain cocks, which will drain out all the water left in them. This is allowed to run into the bilges, which can be pumped out by the donkey pump, or the hand pumps if no steam is left in the boilers.

Some engineers always blow out their boilers after steaming, others do not, the latter only let the fires out and shut the valves in the steam pipes; both plans have their advantages and disadvantages. Perhaps the majority keep the water in the boilers, only blowing out when repairs or an examination of the boiler is required. An engineer should always examine for himself whether all the fires are properly out, and not take the word of the stokers for it. A great amount of damage may be done by the fire not being properly put out in the ash pits. A frequent practice is to get a heap of hot ashes together and dash some water over it; this makes it black outside and leaves it burning inside. The ashes should rather be spread out evenly, and then water thrown over gradually and gently to put the fire out effectually, and to create as little dust and dirt as possible.

EXAMINATION QUESTIONS.

1. Describe briefly the duties to the machinery, when in harbour before getting under steam, that require the attention of the marine engineer.

2. To what must an engineer particularly direct his attention while getting up the steam?

3. When a vessel is under steam, what will then claim the especial attention of the engineer?

4. When a ship is to be laid up in harbour, how must the engines be left?

CHAPTER X.

LAND ENGINES.

The Beam Engine—Horizontal Engine—Vertical Engine—
Portable Engine.

166. The Beam Engine.—The student is referred to
Chapter II.

167. Horizontal Engine.—In this, which is one of the
most convenient and compact form of engine, the general
arrangement is as illustrated in the figure given, although
they vary in detail with the caprice of the maker
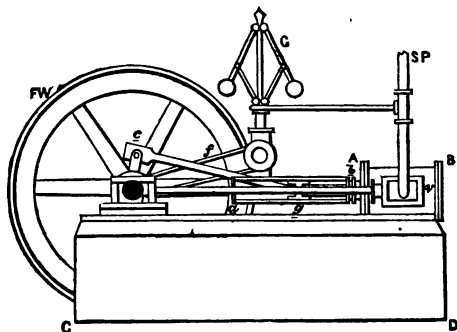
HORIZONTAL ENGINE.

A B is the cylinder lying horizontally on its side, *v* is
the valve to admit the steam from the boiler by way of
the steam pipe S P; the head of the piston-rod is seen
at *g*, the crosshead of which works within the guide or
guide bars *a b*, and to the crosshead of the piston-rod is
attached the connecting rod *g c*, which works the crank
c r. The main shaft is shown at *r*, darkened, this carries
the *fly wheel* F W; *f* is the band working the governor
G by means of pulleys, the driver being on the main shaft;

of course the work is taken off the main shaft *r*.   The whole is generally supported on firm masonry C D.

168. **Vertical Engine.**—In many positions vertical engines are very much better fitted to accomplish the work required than horizontal.   They seem specially adapted for cranes and such like services.

SIDE VIEW   ELEVATION
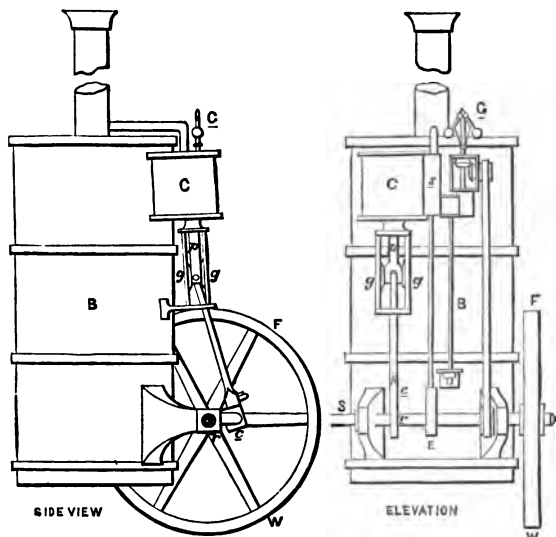
VERTICAL ENGINE.

The letters in both figures correspond.

C is the cylinder, from which proceeds the piston-rod *p*. The head or crosshead of the piston-rod *g* moves in guides *g g*, the connecting rod is *gc*, working the crank *c r*.   The shaft is *r*, which carries the fly wheel F W ; the motion is taken from the end of the shaft at S, or sometimes F W is used as a drum, and the work is conveyed by an endless band ; the governor is placed at G, and the manner in which it works is seen in the right hand figure.

E is the eccentric working the slides at *s*; B is the boiler, to which the framing of the engine is attached, the boiler is generally a vertical tubular one. It is evident from the circumstance of the engine being attached to the boiler, that this class is not intended to give out powerful work.

Vertical engines are frequently used where space is an object, but they have to be rigidly supported to prevent vibration. The slides of vertical and horizontal engines are worked in the usual manner by eccentrics upon the main shaft. Horizontal engines have expansion valves very frequently, which are worked by separate eccentrics; of both kinds of engines the boiler and boiler appendages, such as safety valve, communication valve, pressure gauge, vacuum gauge, gauge cocks, and arrangement of the fireplace, are all the same. Vertical engines are generally non-condensing, and the escape steam is utilized for the blast. Horizontal engines are used both as condensing and non-condensing, but generally the former.
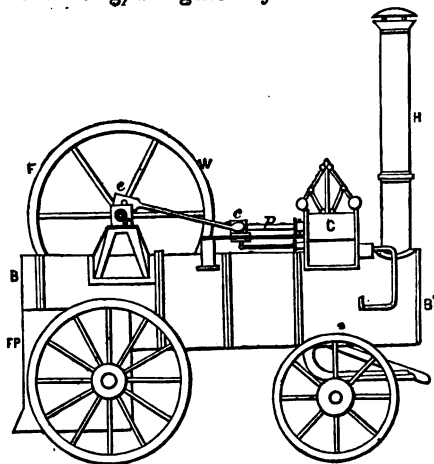
PORTABLE ENGINE.

169. Portable Engine.—A portable engine differs in

no essential particular from an ordinary horizontal engine, excepting that provision has to be made to carry both boiler and engine on two pairs of wheels.

C is the cylinder, the piston of which works the rod p, the crosshead moves in guides or else is kept parallel by guide bars; $c e$ is the connecting rod to work the crank $e s$, the main shaft being s, to the end of which is attached the drum or pulley F W, which also acts as a fly wheel; the slides are worked in the same manner as in ordinary horizontal or other engines by the eccentric; the fire-place is at F P, and beneath it is the ash box; B B' is the barrel of the boiler, which is of the class multitubular; at B' is the smoke box, and H is the chimney. The boiler in a good many points resembles the locomotive; the waste steam is directed from the boiler to the funnel to create a draught, but the cylinder is generally on the top of the boiler, and not under the smoke box. The cylinder, with the pipes connected with it, is sometimes placed inside the boiler, which certainly prevents rain, frost, etc., from condensing the steam in it. The shaft with its pulley or drum, communicates the motion of the engine, by means of an endless band, to whatever machine it has to drive.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. Give a description of a beam engine. Upon what principle is it constructed, and how are the slides worked?

2. Describe a simple and effective form of horizontal engine. What advantages are gained by the use of such engines?

3. How does a vertical engine differ from other engines? State the distinctive arrangements in each case. When may vertical engines be advantageously employed?

4. Describe a simple form of portable engine adapted for agricultural purposes. State clearly how the slides are worked, and how the work is taken off the engine.

5. Explain the manner in which the steam acts in Watt's single acting pumping engine. Why is this engine so much more economical in steam than the old atmospheric engine (1870)?

CHAPTER XI.

THE INDICATOR.

Description—Use—Diagram—Diagrams under Various
Circumstances.

170. The Indicator, an instrument invented by Watt,
is used to ascertain the internal condition of the engine,
the state of the vacuum, the amount and variations in
the pressure of steam at every stroke, the cushioning, the
condition of the slides, whether there be too much or too
little lap or lead, whether they are leaky or properly set,
whether ports are closed and opened at the proper time,
in fact, it tells us the power and all the faults by which
that power is impaired. It may also be attached to the
air pump, the hot well, the condenser, etc., when it will
tell us the nature of the pressures there existing. It
has been very much modified since the time of Watt,
to better adapt it to its purpose. The figure given of
it is from one of Richard's indicators, with all the latest
improvements.

In its simplest form, the indicator consists of a cylinder
with a piston, the top being open to the atmosphere, and
a spring to keep the piston down to its work. A diagram
is taken on a piece of paper to tell us all we wish to learn.
This piece of paper is fastened round a barrel, which
moves through nearly a whole revolution and back again
as the engine makes one stroke.

In Richard's indicator, A is a screw to fasten the
indicator into the cylinder. The handle is to open
the connection between the cylinder and the indicator,

and thus allow steam to enter B D, the cylinder of the
indicator. The piston *a* and piston-rod *b* of the in-
dicator are shown by dotted lines. The slanting dotted
lines are intended for the spring which keeps the
piston down, and against which the steam has to act
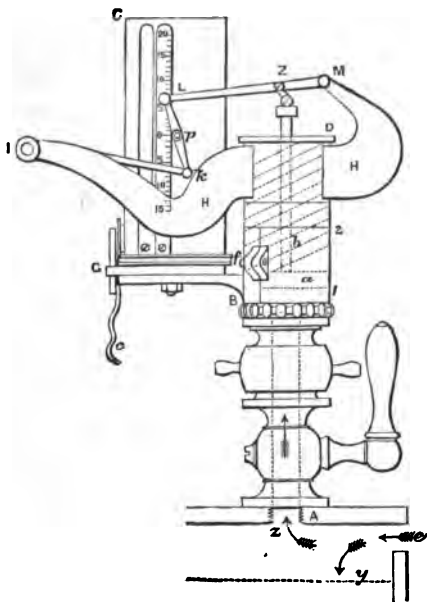
in forcing up the piston *a*. In the actual indicator, the
piston is not so simple as shown here, but is conical and
truncated; B C is the barrel round which the paper is
wrapped. The graduated scale is to measure the pressure
of steam and the vacuum. Within this barrel is a spring,
so that when it has moved nearly round once while
the piston goes up, the force of the spring causes it to
return as the indicator piston goes down. Round the

pulley f G passes a string to give motion to the barrel. This string is attached to the crosshead of the cylinder (or the radius bar), and the motion is reduced in its travel to suit the card barrel. While the piston of the indicator moves up only one to two inches, the piston of the cylinder moves several feet. The barrel has to move round four or five inches in the same time. The motion is reduced by levers when taken from the piston crosshead. If the length of the diagram be three inches, and the stroke three feet or thirty-six inches, we have only to proportion the levers as $3 : 36$ or $1 : 12$, and the required motion is found. The indicator barrel is moved round by the string (shown in the figure, being attached to its proper relative position on the lever, and) actuating the pulley f G, and with it the barrel. The arm H H is to carry the parallel motion I k L M, the pencil being at p. The reason of this arrangement (*i. e.*) of having a parallel motion, is that while the stroke of the indicator is (say) only from 1 to 2, the pencil is required to move up and down from the lower fifteen to (say) twenty. The head of the indicator piston being attached to the lever M L at Z, multiplies the motion of the indicator in the proportion of M Z to Z L. In Richard's indicator this multiplier is about three and a half; in fact, this is the essential difference between Richard's and other indicators, such as M'Naught's, Maudslay and Field's, etc., that the motion is magnified, and therefore the pencil more sensibly indicates the least variation of pressure or action.

The action of the indicator must now be traced. Supposing the indicator is attached to the cylinder, but not placed in communication with it by turning the handle, and that the cord c is fastened to the lever at the head of the piston-rod, then it will move the barrel from right to left, and a straight horizontal line will be drawn by the pencil, as A B in next figure—it is generally customary to let the pencil mark this line several times. The line is called the atmospheric line, because it coincides

with the atmospheric pressure; all parts of the diagram
above that line show pressure above the atmosphere, all
parts below it show the vacuum, hence the top part of
the diagram is called the "steam" and the bottom the
"vacuum." Again: supposing the barrel were still, and
the steam admitted to the indicator, the pencil would be
driven straight up, or a vertical line would be traced.
We see that if the barrel only move, a horizontal line
is traced, while if the indicator piston only move, a
vertical one is made; therefore, when both move together,
we shall have a line compounded of the two motions, and
if the one is continually changing, it will not be a diagonal
motion.
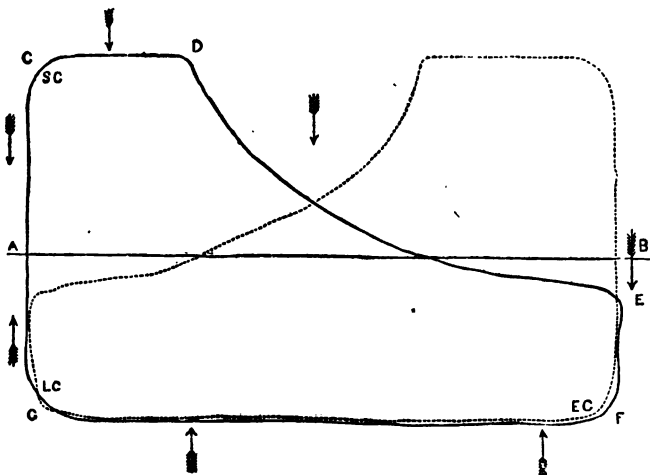
DIAGRAM.

Let us suppose the indicator is attached to the top of
the cylinder, and that steam enters the upper port e as
the piston comes to the top of its stroke. The moment
steam enters the cylinder it drives the piston down, but

at the same time it enters the indicator, and drives the piston of the indicator up.

Let us suppose the pencil (when air is in both sides of the piston) stands at A on the foregoing figure, then the line A B, which will be traced by the barrel moving nearly the whole way round, is the atmospheric line. Now let us suppose the top port *e* opened at the instant the tap of the indicator is turned, then steam will rush in, in the direction shown by the arrows; in the direction *y* to drive down the piston, and in the direction *z* to drive up the piston of the indicator. Steam coming in instantaneously drives up the pencil, and the line from A to C will be drawn (C is called the starting corner). Now steam continues rushing in at its normal pressure and the piston of the engine goes down, while on the indicator piston the pressure is continuous, so therefore the pencil remains at the same height, and as the barrel moves round, the line from C to D is drawn. When the pencil gets to D the slide has come down again and closed the port,* so that the steam is left to expand; and of course as it expands its pressure decreases, the engine piston continues to go down, and the pressure, becoming less and less in the indicator, the pencil gradually falls lower and lower to E. When it gets to E, the slide still falling, the upper port *e* is opened to the exhaust, and the steam rushes out in a contrary direction to the arrows, the pencil therefore immediately falls to F (the eduction corner). Now there is a vacuum above the piston of the engine, and below that in the indicator, and the engine piston begins to rise up; all the time it is rising, there being no steam or pressure in the indicator (or less than no pressure), the pencil, having fallen to its lowest point, is still, and traces the vacuum line F G to the lead corner G. Against the pencil gets there, the piston has arrived at the top of its stroke, the cushioning then takes place,

* We are supposing a long D slide is used. In reading the paragraph, the student must consider both this figure and the last on page 153.

and the pencil rises at once to A, or else the lead comes
into action by the rising of the slide, and drives the in-
dicator piston, and with it the pencil, to A.

The action of the indicator has been traced through an
up and down stroke, or a complete revolution of the
crank, and we see that the varying pressure in the cylin-
der is faithfully translated by the indicator, and rendered
visible to the eye.

The indicator is absolutely necessary if we are to know
the pressure of steam when it is performing its work.
The Bourdon gauge or other contrivance, when correctly
graduated, will always tell the boiler pressure, but it
must be well understood that the boiler pressure seldom
or never corresponds to that in the cylinder, it is less.
This diagram is supposed to be taken from the top of
the cylinder, and the arrows show the direction in which
the piston of the engine is moving when that part of the
diagram is being traced.   The dotted diagram represents
one taken from the bottom of the cylinder.

The corners of the diagram are the points to which
attention must be directed to find out any defects.   In
the diagram from a non-condensing engine, the whole of
the curve is above the atmospheric line; but in a con-
densing diagram part is above the atmospheric line and
part below.

This is the normal indicator diagram, and all condensing
engines in good working order, with slides properly set
and rods of correct length, should give a similar diagram.
We will note what the change would be under certain
conditions.

If the curve in starting from A ran to the left of C
instead of vertically, then we should know that the
steam was late in its action, or the slide (the long D)
was not high enough at the proper moment.   If the
curve at E were a little higher and a little farther to the
left, the exhaust would take place too early, or the upper
part of the slide would be too low.   Both the changes
would take place through the slides being too far down

in the casing, or if the slide rod or eccentric *rod were too long.*   Such an evil would also be shown by the diagram being fuller at G, or coming a little farther to the left, and the steam would be cut off too soon at D.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. By what apparatus can you obtain a diagram on paper which will inform you as to the amount of the pressure of the steam or uncondensed vapour in the cylinder during each portion of the stroke of the piston.   What would be the probable form of the diagram in a condensing engine (1870)?

2. Describe the indicator.   Show how it may be used to find the effective horse-power of an engine (1868)?

3. Draw a nominal indicator diagram (1867)?

4. Show by an indicator diagram the advantage of expansive working over throttling (1867)?

INDEX.

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